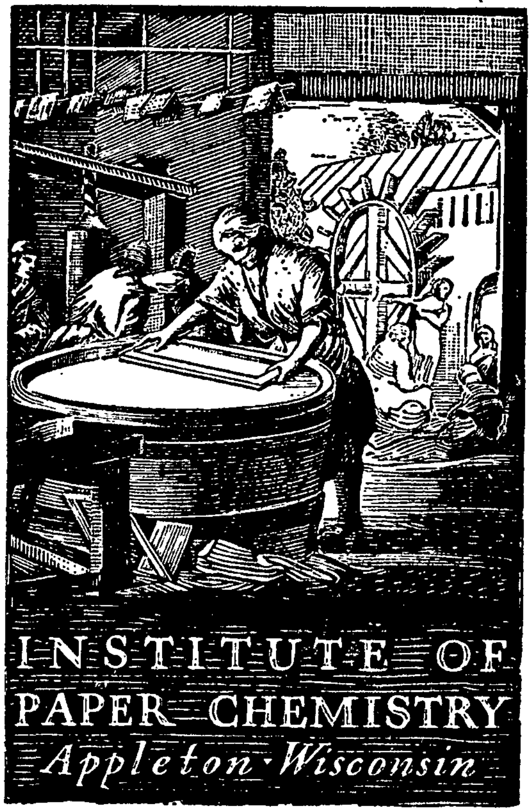

CHARACTERIZATION OF PULPS FOR PAPERMAKING

CHARACTERIZATION OF FOUR STOCKPILE PULPS

Project 2406

Report Seven

A Progress Report

to

MEMBERS OF GROUP PROJECT 2406

March 8, 1967

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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Albemarle Paper Company
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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

CHARACTERIZATION OF PULPS FOR PAPERMAKING

CHARACTERIZATION OF FOUR STOCKPILE PULPS

SUMMARY

This report presents the results of work done to characterize four dry-lap market pulps. These four pulps were selected to represent a broad range of papermaking properties, and were stored to provide a stockpile for continuing use in the pulp characterization program. The pulps which were selected were a bleached western softwood sulfite, an unbleached southern-pine kraft, a bleached northern hardwood kraft, and a bleached northern softwood kraft. Descriptive data supplied by the manufacturers of each of these pulps are presented to allow the reader to compare these pulps to those with which he may be familiar.

In this initial characterization of these four pulps, the fiber dimensions, fiber strength, and bonding characteristics of each pulp were measured for samples which had been beaten up to sixty minutes in a Valley beater. These three pulp characteristics have been shown to have an important effect on the strength properties of paper.

The fiber length distributions for each of the beaten pulps were measured. Distinct differences in the "cutting" resistance of the four pulps were noted. The bleached sulfite pulp was the least resistant to cutting, and the unbleached southern pine kraft was the most resistant. The apparent coarseness values of the unbeaten pulp ranged from 18 mg./100 meters for the hardwood to a value of 53 mg./100 meters for the unbleached southern pine kraft.

The fiber strength was measured using the zero-span tensile test and was at approximately the same level for all four pulps.

The bonding characteristics were measured by an improved dynamic nitrogen-gas adsorption method, the measurement of optical scattering coefficient, and the perpendicular (Z) tensile test. Good correspondence was found between the scattering coefficient and the gas adsorption area, but no correlation was found for the (Z) tensile test.

The filtration properties of the pulps were measured to characterize both their drainage rates and also to provide data on the more fundamental properties of hydrodynamic specific volume and hydrodynamic specific surface. The hydrodynamic specific volume of the pulp, calculated from the filtration resistance and the wet-mat compressibility, was used as an indication of the swelling of the pulp, its conformability, and hence its bonding capability. Data for the common Canadian and Schopper-Riegler freeness tests are given to provide a relative comparison with data on similar pulps beaten by comparable means. An excellent general correlation was found between the Canadian Standard freeness and the filtration resistance measured at a single arbitrary pressure drop of fifty centimeters of water. The data for all four of the pulps fell on a common curve over the range of beating which was studied.

The Institute in-plane tear test was performed together with the more common breaking length, burst factor, and Elmendorf tear factor. The lack of direct correlation between the two tear tests was ascribed to the difference in mechanical conditions at the zone of tear. The in-plane tear energy increased twofold with beating for the unbleached southern-pine kraft, while over the same beating range the Elmendorf tear factor decreased to one-half its original value. The usefulness of each test depends, of course, on the actual mode of tear which occurs in a particular application.

Handsheet data are presented in this report as an arbitrary, though well-known, papermaking process to illustrate the interpretation of paper properties in terms of fundamental characteristics. It is, of course, recognized that individuals in the member companies will want to extend this interpretation to their own experience in commercial papermaking operations.

In addition to the graphical presentation of data and comments regarding the influence of each of the measured pulp characteristics on the paper properties, three possible uses for these data are reviewed. These three methods are: 1. statistical, 2. pragmatic, and 3. theoretical. The limitations of the statistical and direct theoretical approaches were pointed out, thus leaving the pragmatic approach, supplemented by the insights of the theoretical method, as the most practical present approach.

INTRODUCTION

This report presents data obtained by a variety of techniques on four commercial pulps. This work was initiated for a number of reasons as discussed in the technical meeting in November, 1965 and in our letter of January 26, 1966. In the past, the terms "reference" or "standard" pulps have suggested several interpretations and consequently various objectives and lines of attack. The different objectives are not necessarily contradictory and any given one may be highly desirable and justified for a specific company's needs, but not necessarily justified in a group-sponsored effort. For example, the correlation of "fundamental" characterizations of a pulp with its actual performance on the paper machine has been discussed but avoided (in the group-sponsored project) because of the numerous ramifications that would be required to make a significant correlation for the wide range of machines and grades of paper of interest to the sponsors.

On the other hand, there are benefits to be gained by some aspects of the reference pulp idea and we have adopted the concept of "stockpile pulps" for the following purposes.

1. To provide a stockpile of pulps which will be available for use in all research in this general area whenever a commercial pulp is suitable. This will provide a maximum of information with minimum duplication and a better base for comparison of future developments.
2. To provide a variety of pulp characteristics for periodic attempts to test and illustrate developments of various procedures by application to actual commercial pulps.

3. To illustrate to the sponsors the application and potential significance of these techniques to pulp types whose paper-making performance can be recognized in at least a qualitative sense by the sponsors of the program.

These pulps are not intended to represent a standard of performance against which other pulps are compared and therefore we have avoided the terms reference or standard pulp.

With these objectives in mind we solicited suggestions from the sponsors of the project and ultimately selected four stable, dry-lap market pulps as our basic stockpile to represent the following types:

A. (or 1) - West Coast Softwood Bleached Sulfite

B. (or 2) - Unbleached Southern Pine Kraft

C. (or 3) - Bleached Northern Hardwood Kraft

D. (or 4) - Bleached Northern Softwood Kraft

In order to identify the general performance characteristics of these pulps with your experience to the greatest practical extent, we have included all the information furnished by the supplier. In addition we have tested them by the conventional pulp testing procedures and have included these data in our report.

In addition to the conventional tests we have also included those characterizations from the pulp evaluation program which appeared to us to have reached a stage of development where their application could be illustrated. This does not mean that any of these tests have reached the ultimate degree of refinement (and this will be obvious as you study this report) but we hope that these tests will be of interest and stimulation in suggesting applications in your own laboratories.

With all these data available, we have made a limited application of crossplots and attempts to illustrate the significance of these tests. Where these correlations involve handsheets, we recognize that the tests made in the laboratory on handsheets are arbitrary tests (which the industry has found useful) but which do not pretend to encompass the entire range of papermaking performance which might be expected from these pulps.

The pulp characterization programs that preceded Project 2406 produced a number of reports concerning the comparison of physical test data, their correlation, and some application and interpretation of these data on a broad, integrated front. Reports which have taken this approach were: under Project 1513: Reports Five, Sixteen, Eighteen, Nineteen; under Project 2210: Report Sixteen; and under Project 2211: Reports One, Three, Six, and Eight. Unfortunately, these studies were not performed on pulp which could provide a stable stockpile to ensure continuity and comparable results in future work.

This report draws together data which have been collected on the characteristics of the stockpile pulps measured according to currently available techniques and compares these characteristics with data on handsheets made from the same sample. The data will form a base for further work using these pulps in the improvement of tests for pulp characterization and also will help to show the applicability of fundamental characteristics to the interpretation of paper properties. In the present report, these interpretations are restricted to handsheets, but it is assumed that the cooperators have information on the comparable machine performance of similar pulps so you will be able to also interpret your commercial data in terms of fundamental pulp properties.

The tests used to characterize the pulps have been grouped into five main categories: 1. drainage properties, 2. fiber dimensions, 3. fiber strength, 4. bonding, and 5. the resultant handsheet properties. The tests which were made are listed in Table I.

TABLE I

TESTS PERFORMED ON STOCKPILE PULPS

Drainage Properties

- Canadian Standard Freeness
- Schopper-Riegler Freeness
- Filtration Resistance (Research Model)
- Filtration Resistance (Commercial D.R.A.)
- Hydrodynamic Surface and Volume (calculated from filtration resistance and wet-pad compressibility)

Fiber Dimensions

- Fiber-Length Distribution (projection)
- Grid-Count Fiber Length (for a few samples)
- Number and Weighted Average Length (calculated from distribution)
- Coarseness (for unbeaten pulps)

Fiber Strength

- Zero-span Tensile Strength

Bonding

- Unbonded Area of Handsheets (by dynamic gas adsorption)
- Specific Scattering Coefficient
- Perpendicular (Z) Tensile Strength
- Area of Water-Dried, Unbonded Fibers

Handsheet Properties

- Breaking Length
- Burst Factor
- Elmendorf Tear Factor
- Institute In-Plane Tear Energy
- Stretch
- Tensile Energy Absorption
- Sheet Moisture
- Basis Weight
- Thickness
- Ovendry Density

PULPS

Each pulp was procured in a one-ton lot taken from standard production of a market pulp mill. The bales were opened, the contents sampled in a representative manner, and repackaged in smaller quantities. To minimize subsequent changes, each pulp was allowed to age for several months before testing.

The following descriptions of each pulp are based on information supplied by the manufacturer.

Pulp "A" (or No. 1)— West Coast Softwood Bleached Sulfite.

This pulp was chosen to duplicate, as nearly as possible in a current market pulp, the wet-lap pulp which had been used in a major part of the previous work in the pulp evaluation program. (From previous reports it will be obvious that this is a Weyerhaeuser pulp.) This pulp is made from Western Hemlock by a bond paper type of cook and fully bleached in a three-stage system consisting of chlorine, caustic extraction, and buffered hypochlorite. In the early pulp evaluation program, this grade was known as "Standard" but today is labeled "W." The following information was also furnished by the supplier:

Air dry	88.8
G.E. tab	90.2
G.E. TAPPI	91.0
Dirt count	55
Appearance	24
Shives	1
Viscosity	222
Physical tests at 250 cc. C.S.	
Burst	60.7
Tear	77.0
Fold	1180
Break	8000
Time	64

Pulp "B" (or No. 2) — Unbleached Southern Pine Kraft Pulp.

This was defined by the supplier as a paper-grade southern pine kraft, intermediate between bleachable and liner grade pulp. The wood species was described as mixed southern pine with over 50% being loblolly. Pulp was cooked by the kraft process in a Kamyr digester, flash-dried and compressed to a density of 50 lb./cu. ft.

Pulp "C" (or No. 3) — Northern Hardwood Bleached Kraft Pulp.

The following information was released by the manufacturer.

<u>Approximate Wood Species Distribution</u>

55% maple (red and some sugar)
20% birch (yellow and white)
15% beech
10% elm, oak, ash

<u>Cooking</u>

Batch digesters - 3000 $ft.^3$
Direct steaming, with circulation
17% active alkali based on o.d. wood = liquor/wood = approx. 3.3/1
30% sulfidity, 81% activity liquor

Cooking time = 0.75 hour to plus 1.50 hr. at 167°C.
K No. = 10.5 - 11.5

<u>Bleaching</u>

Four stage C-E-H-D to 86 - 88 G.E.
C = chlorination (chlorine water)
E = extraction (sodium hydroxide)
H = sodium hypochlorite
D = chlorine dioxide

Pulp "D" (or No. 4) — Northern Bleached Kraft.

This is 100% jack pine.

PULP PREPARATION AND TESTING

Each stockpile pulp was beaten in a well-calibrated Valley beater over the same range of beating time. The samples were conditioned at standard temperature and humidity (70°F. and 50% R.H.) before weighing each beater charge, and the sample was soaked overnight in deionized water before dispersing with a Williams disk and beating. The beating order of the pulps and the run times were carefully randomized to prevent any spurious results due to the possible changing conditions of the Valley beater, and each beater run was made in duplicate. Because of the large number of tests to be performed on each sample, it was not practical to make a single standard beater run to obtain the necessary beaten pulp at each interval. Instead the pulps were beaten to a given time and the entire beater charge was dumped. Such tests as could be made immediately, such as handsheets, freeness, and other measurements, were made and then a sample was stored in a cold room at 4°C. at beater consistency to be used for the further tests. The remaining tests were performed within a few weeks after the beater runs. Other work here at the Institute has shown that storage in the cold room at beater consistency produces very little change in the physical properties of pulps.

Each test was performed according to the applicable TAPPI or Institute standard procedure with proper attention to the necessary details in each case. Handsheets were made on a standard British mold and in all cases, except for zero-span breaking length and z-tensile strength, were of the standard 1.2-gram weight. Zero-span sheets were 1.0 g.; z-tensile, 2.4 g. Experimental data derived from these tests are shown in Appendix I.

The first column in Appendix I shows the code number of a particular beaten pulp. The first number signifies the pulp itself (1, 2, 3, or 4 being A, B, C, or D) and the second two digits signifying the number of minutes that particular pulp was beaten before being dumped. The columns are arranged according to test number or test code and the test code is given in the table at the beginning of Appendix I (for example, Column 2 is Canadian Standard Freeness). These data are the averages of the two duplicate beater runs.

THE GRAPHICAL PRESENTATION OF DATA

It is very difficult to judge the relative trends in data from a direct tabulation of the numbers. In recognition of this fact, frequent use has been made in this report of the graphical presentation of data. Reference can be made to the detailed tabulation for specific data values, but, for the most part, the relative values as plotted on a graph have been used. The excellent facilities of the Institute's Computing Center have been used to produce the graphs and figures, together with the appropriate legends and symbols, directly from the data table using a digital computer and an on-line digital plotter. The speed with which these graphs can be produced greatly compensates for the fact that some of these graphs lack the "finish" of hand-drawn and lettered figures. It is entirely practical to select a particular pair of tests and have the computer plot the data for all four pulps, together with proper identification, at a rate of two minutes per graph. If an abbreviated form of the axis identification is permissible, the plotting time can be reduced to approximately twenty seconds. As will be evident from the following sections, a great deal of use has been made of this fast and convenient method of scanning the data, investigating correlations, and illustrating particular relationships.

All the data in Appendix I has been plotted in Fig. 1-23 on the following thirteen pages to show the relative trends of the test values with beating time. The same symbols are used in all the graphs in this report to identify each pulp, and with a little use, they will become familiar. The symbols used are as shown in Table II (p. 26).

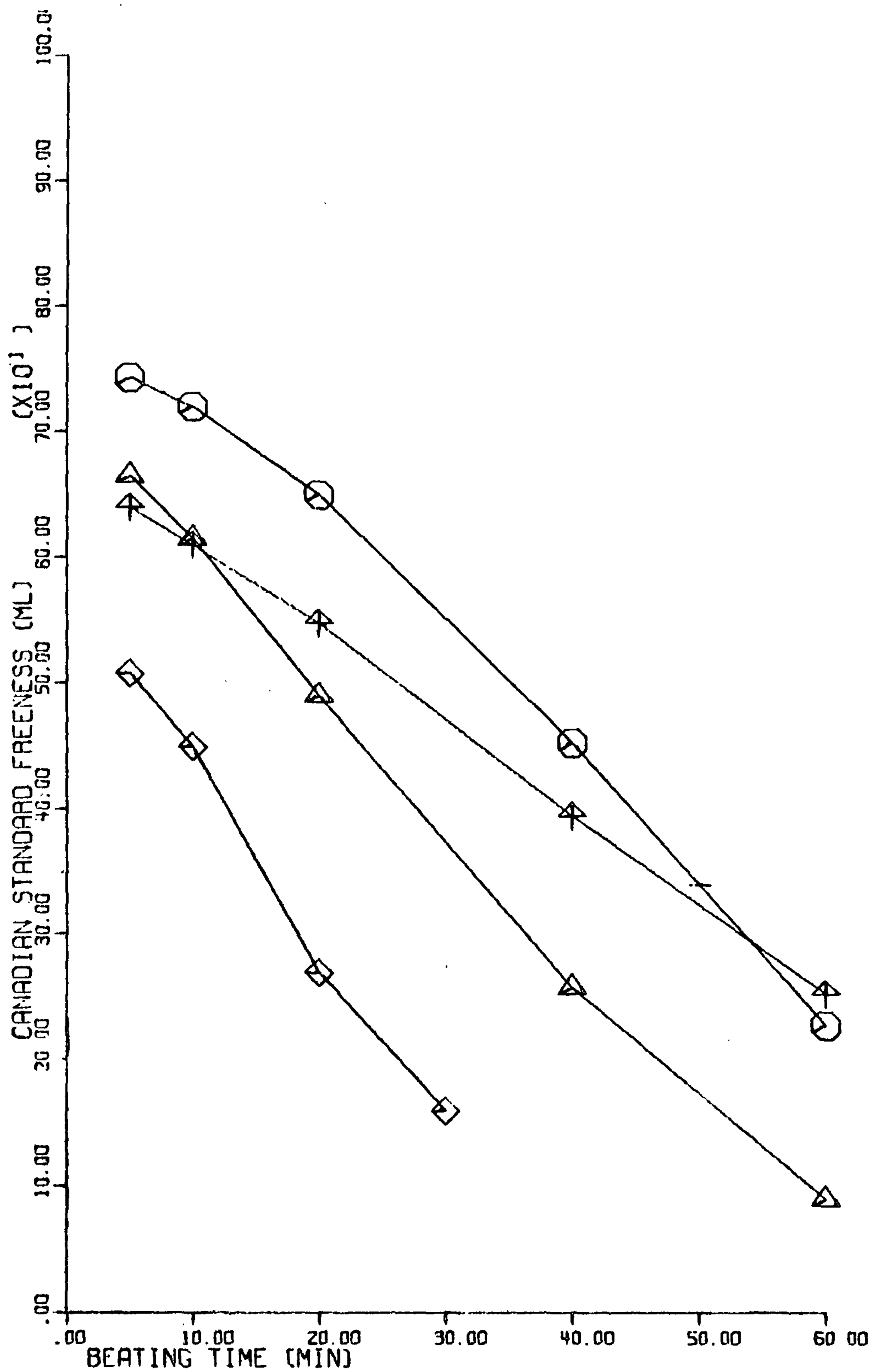


Figure 1. Canadian Standard Freeness *Versus* Beating Time for Four Stockpile Pulps

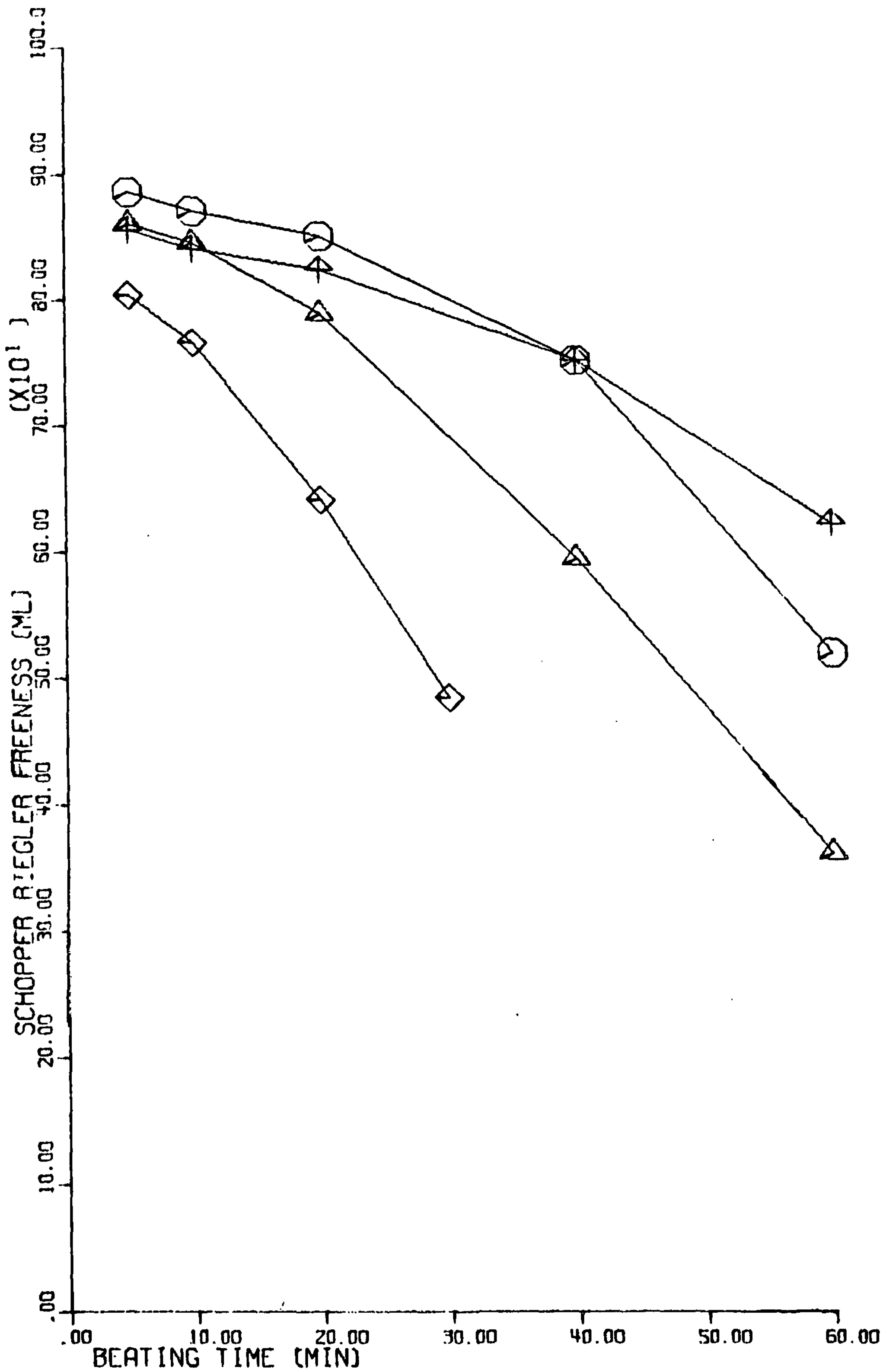


Figure 2. Schopper-Riegler Freeness Versus Beating Time

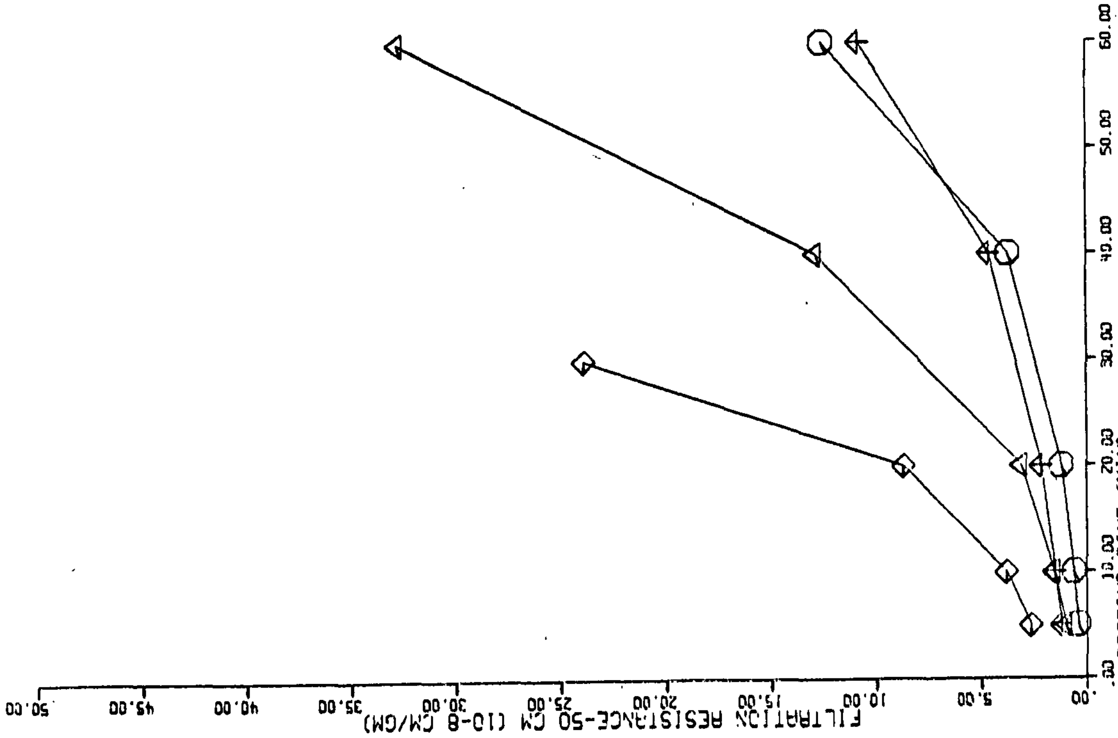


Figure 3. Filtration Resistance at an Overall Pressure Drop of Fifty Centimeters of Water (Research Apparatus)

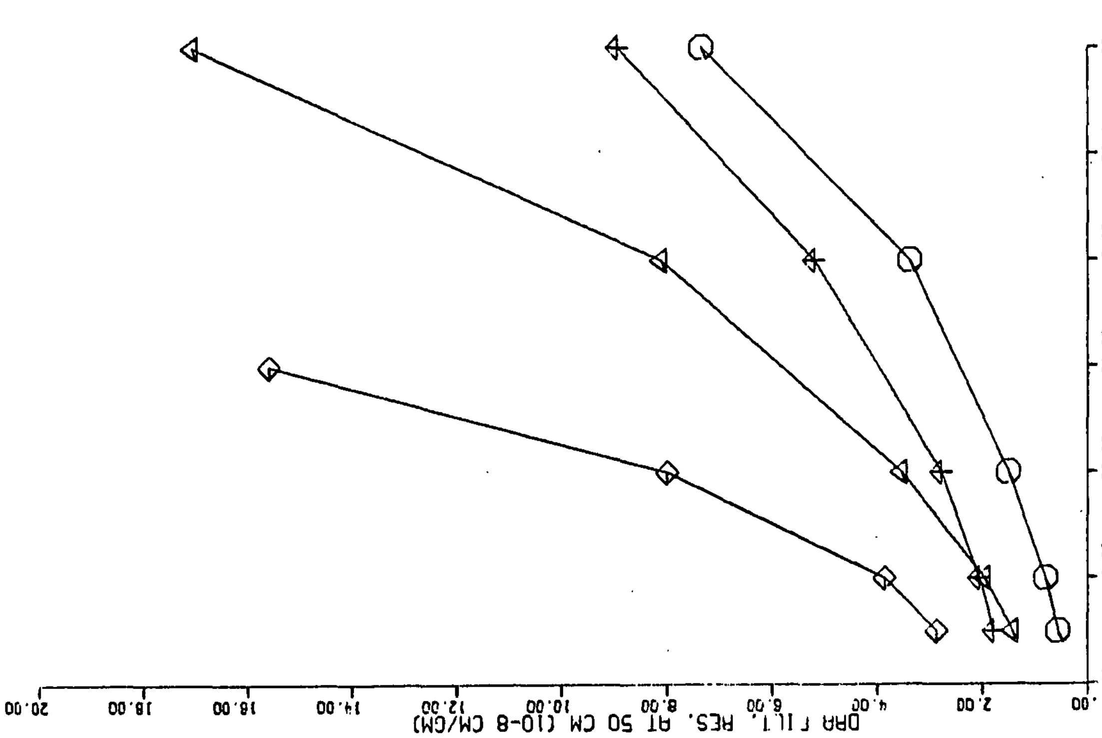


Figure 4. Filtration Resistance Measured on the Commercial D.R.A.

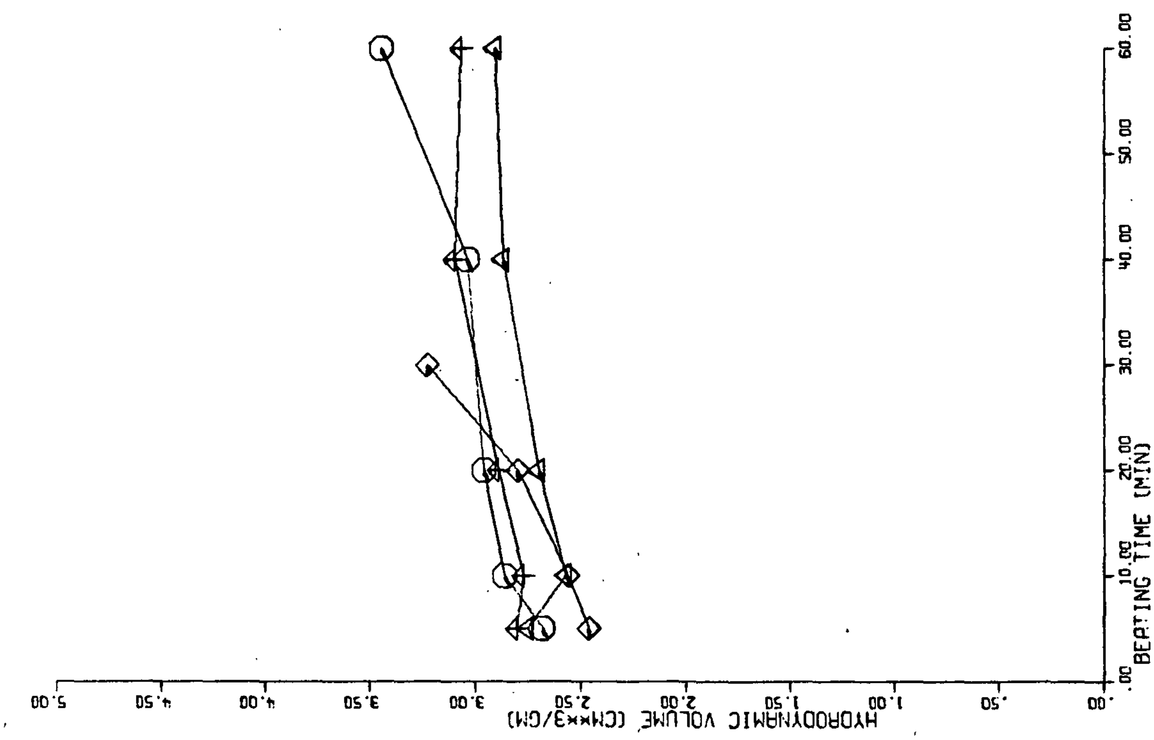


Figure 6. Hydrodynamic Volume Versus Beating Time

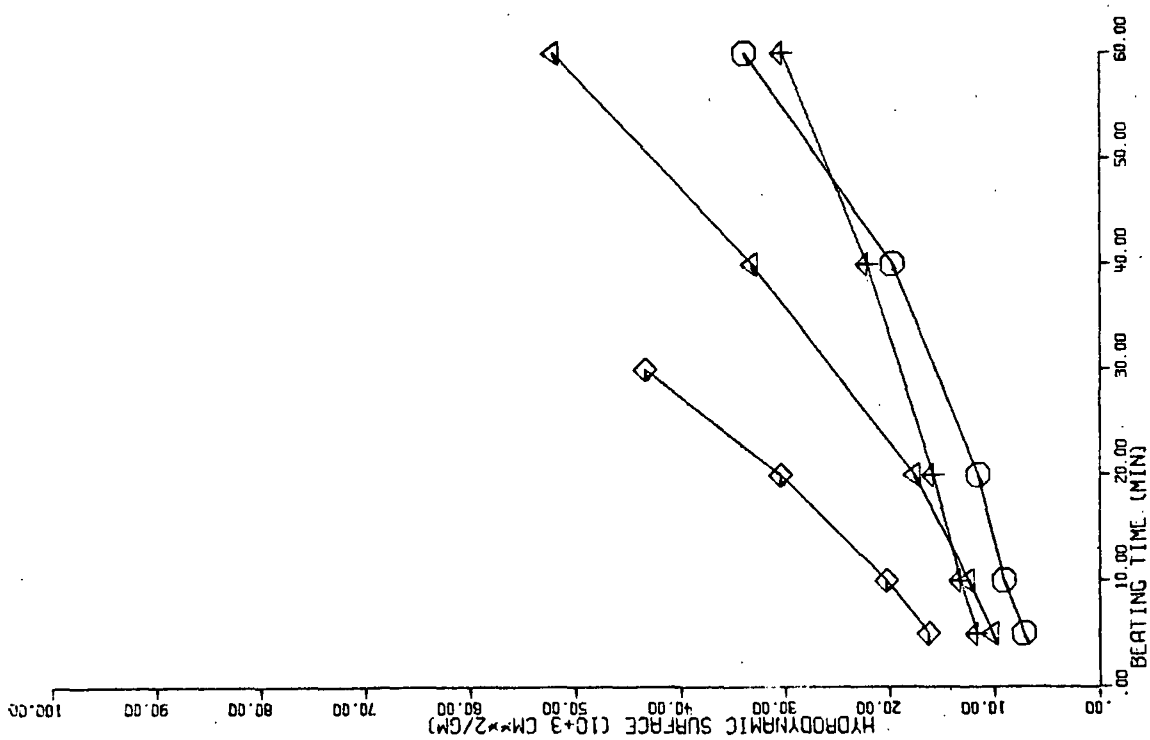


Figure 5. Hydrodynamic Surface Versus Beating Time

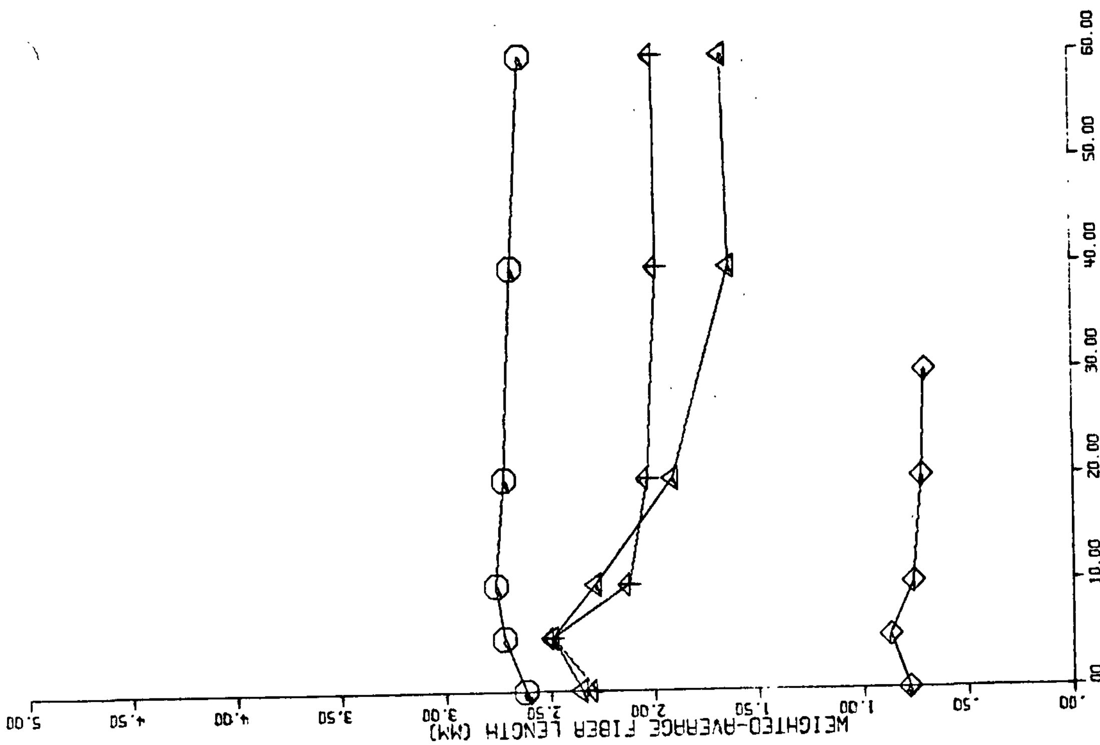


Figure 8. Weighted-Average Fiber Length Versus Beating Time

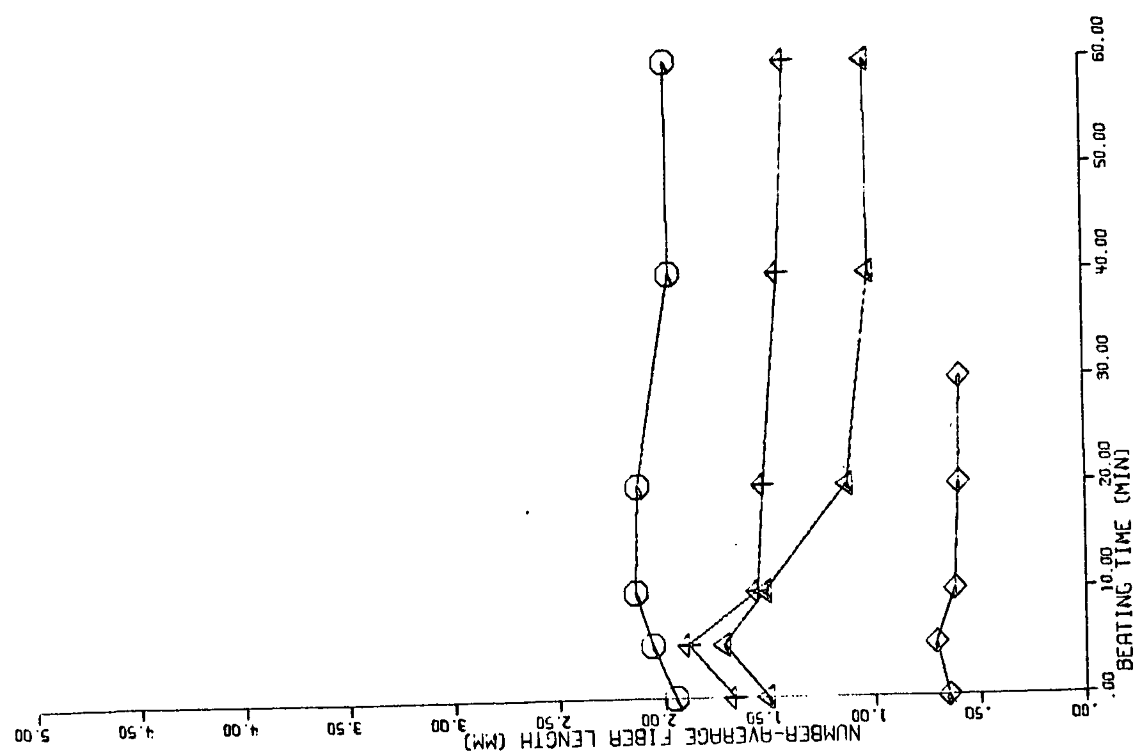


Figure 7. Number-Average Fiber Length Versus Beating Time

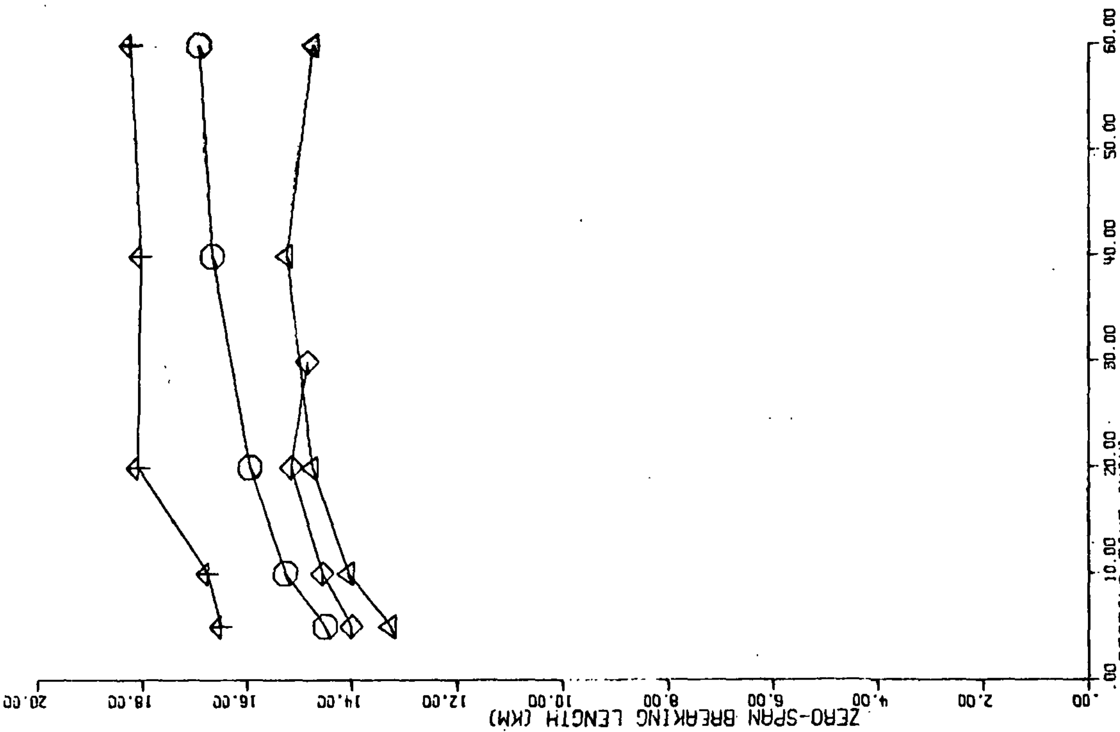


Figure 9. Zero-Span Breaking Length for Four Stockpile Pulps

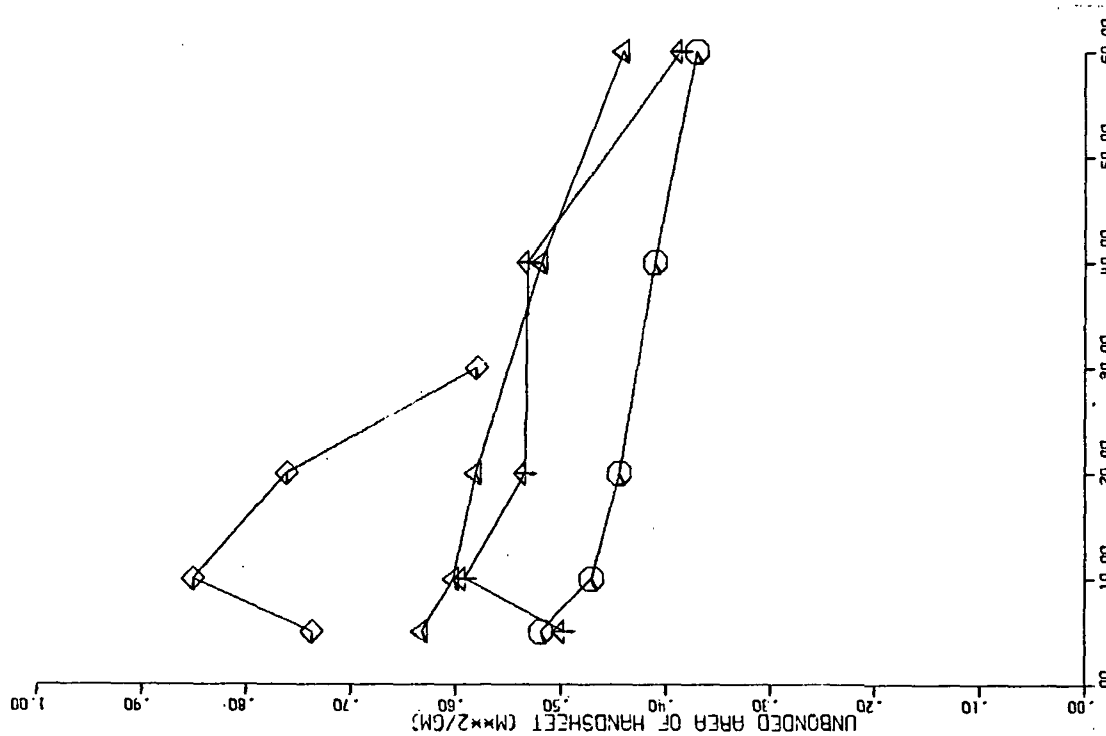


Figure 10. Unbonded Area of Handsheets as Measured by Dynamic Nitrogen-Gas Adsorption

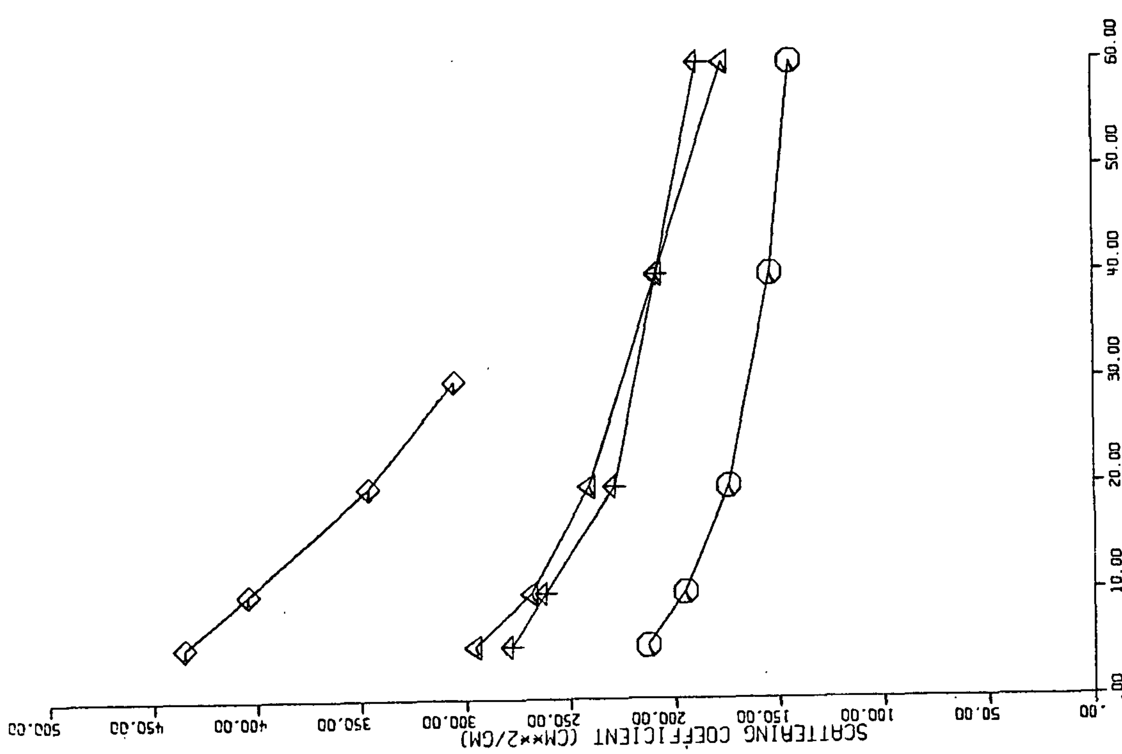


Figure 11. Specific Scattering Coefficient <u>Versus</u> Beating Time for Four <u>Stockpile</u> Pulps

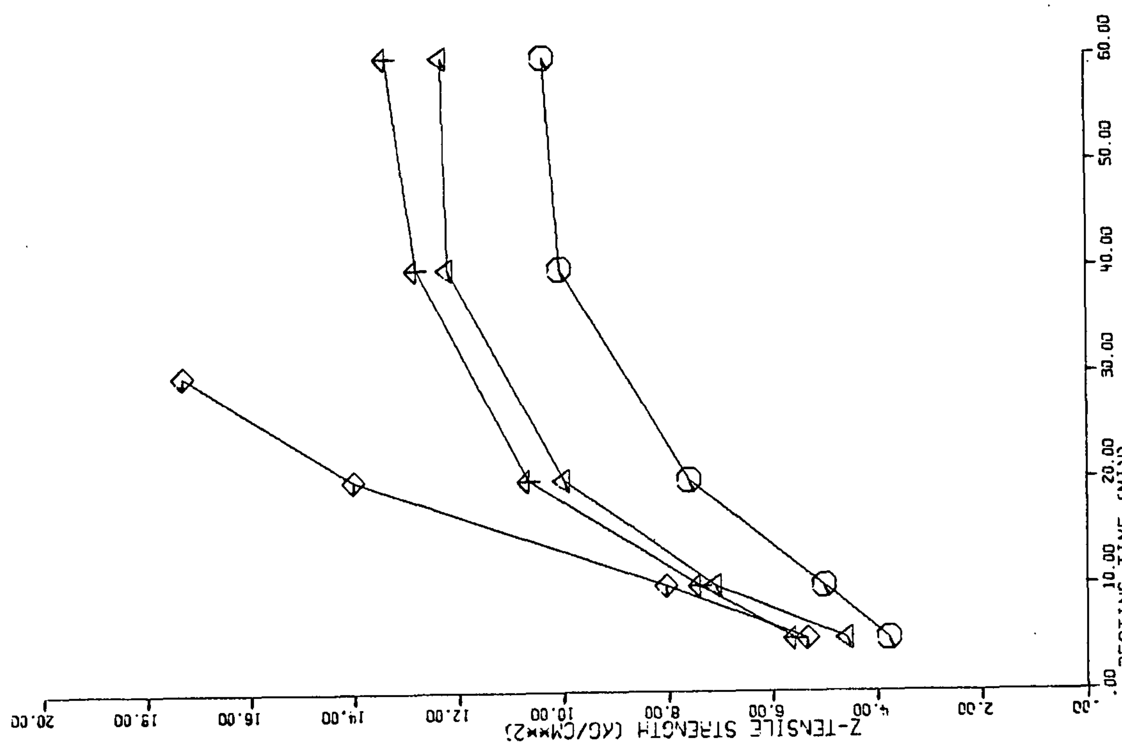


Figure 12. Perpendicular (Z) Tensile Test <u>Versus</u> Beating <u>Time</u>

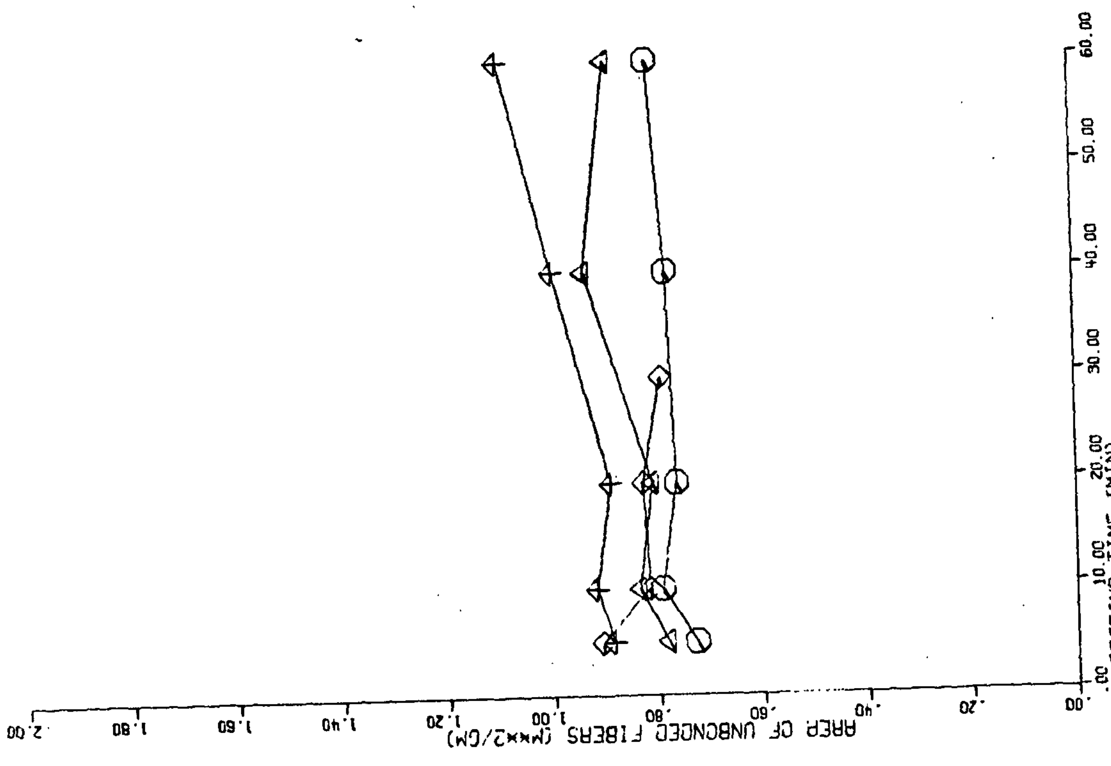


Figure 13. Area of Unbonded, Water-Dried Fibers as Measured by Dynamic Nitrogen-Gas Adsorption

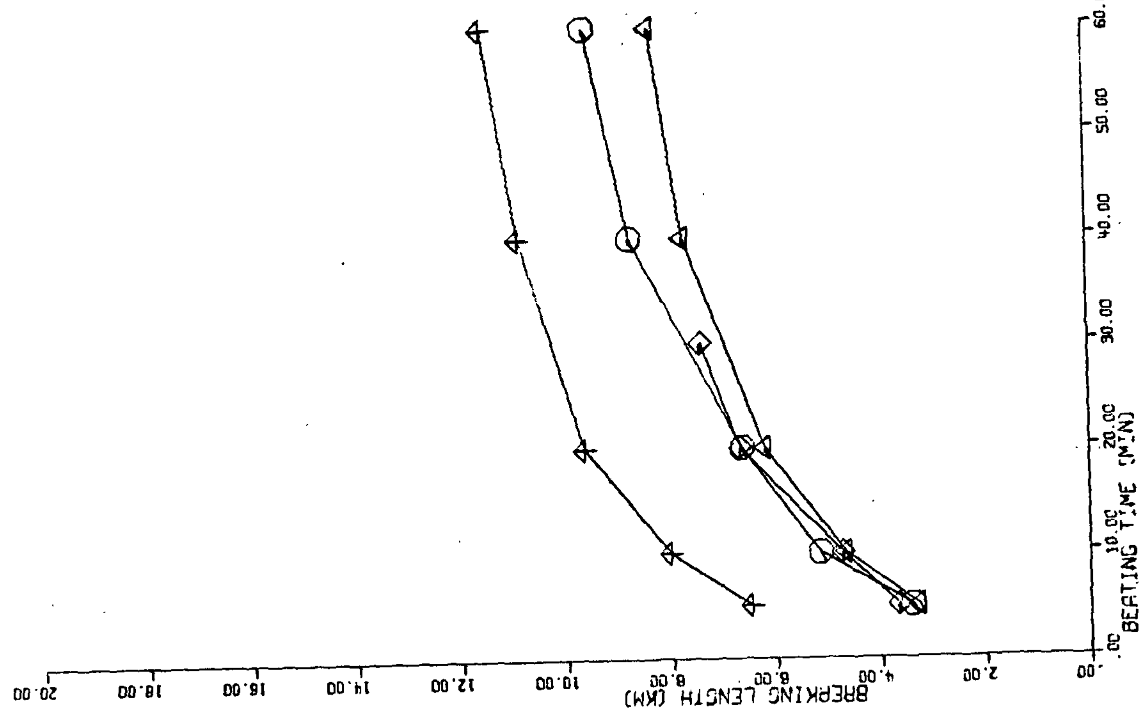


Figure 14. Breaking Length as a Function of Beating Time for the Four Stock-pile Pulps

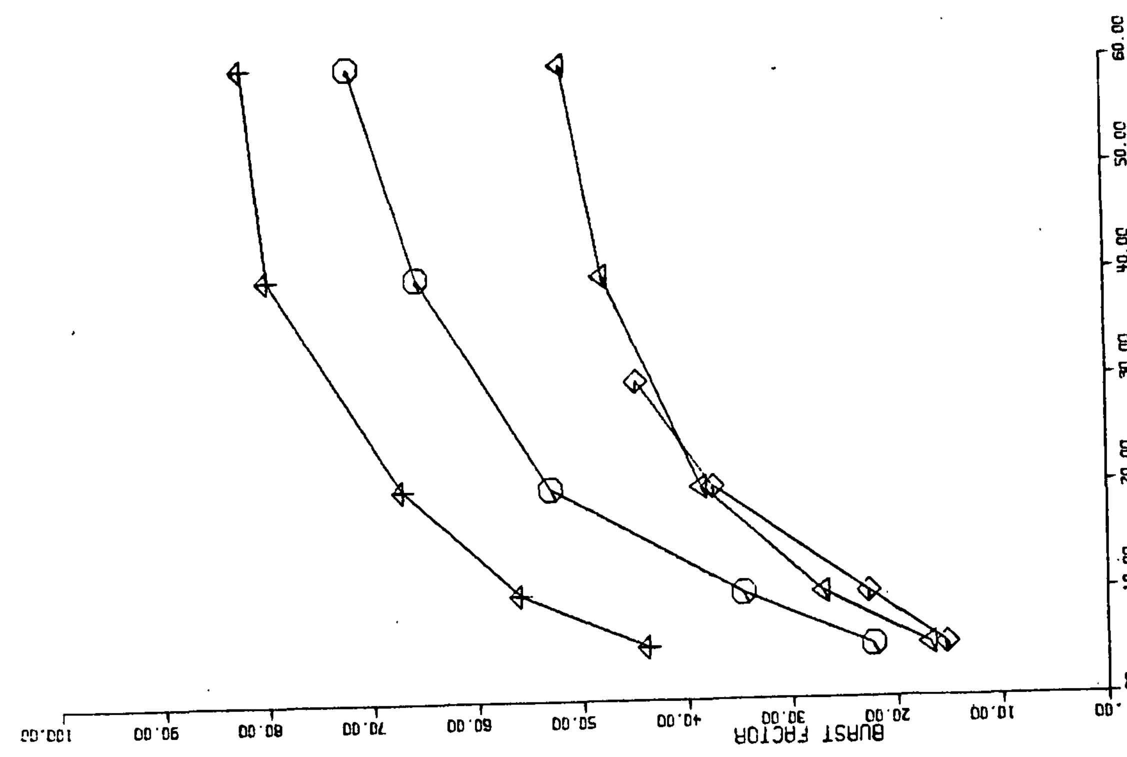


Figure 15. Burst Factor for Four Stockpile Pulps as a Function of Beating Time

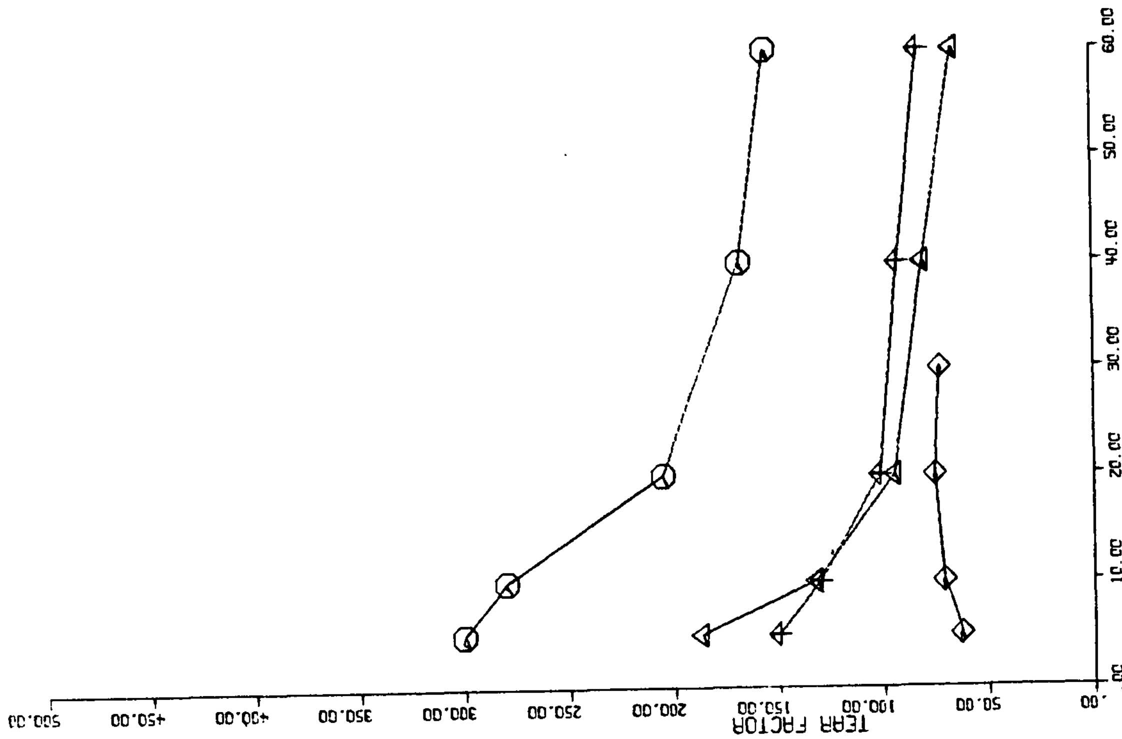


Figure 16. Elmendorf Tear Factor Versus Beating Time

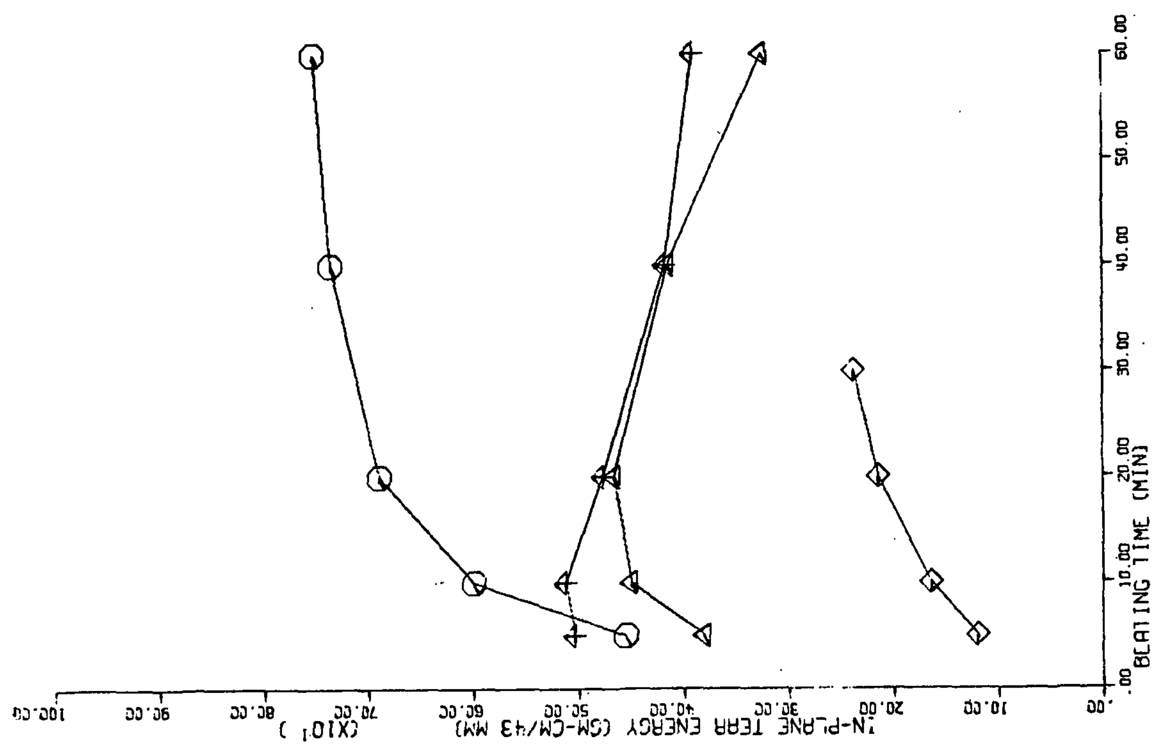


Figure 17. Institute In-Plane Tear Energy Versus Beating Time

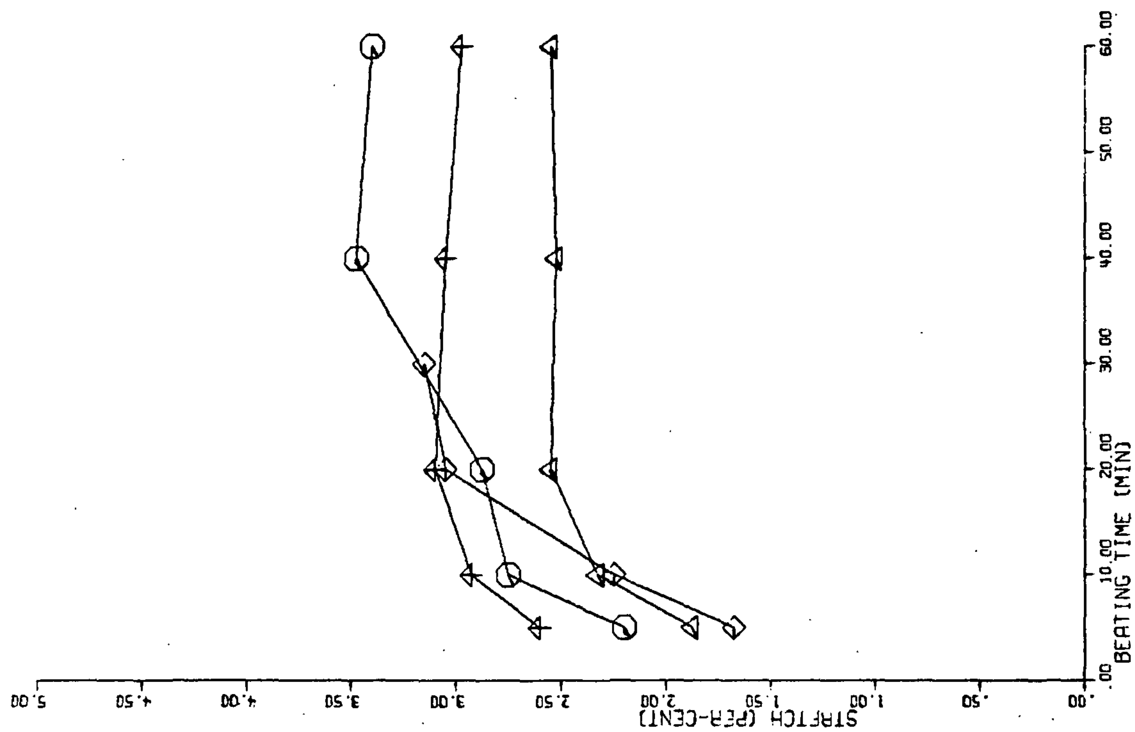


Figure 18. Elongation at Break (Stretch) Versus Beating Time

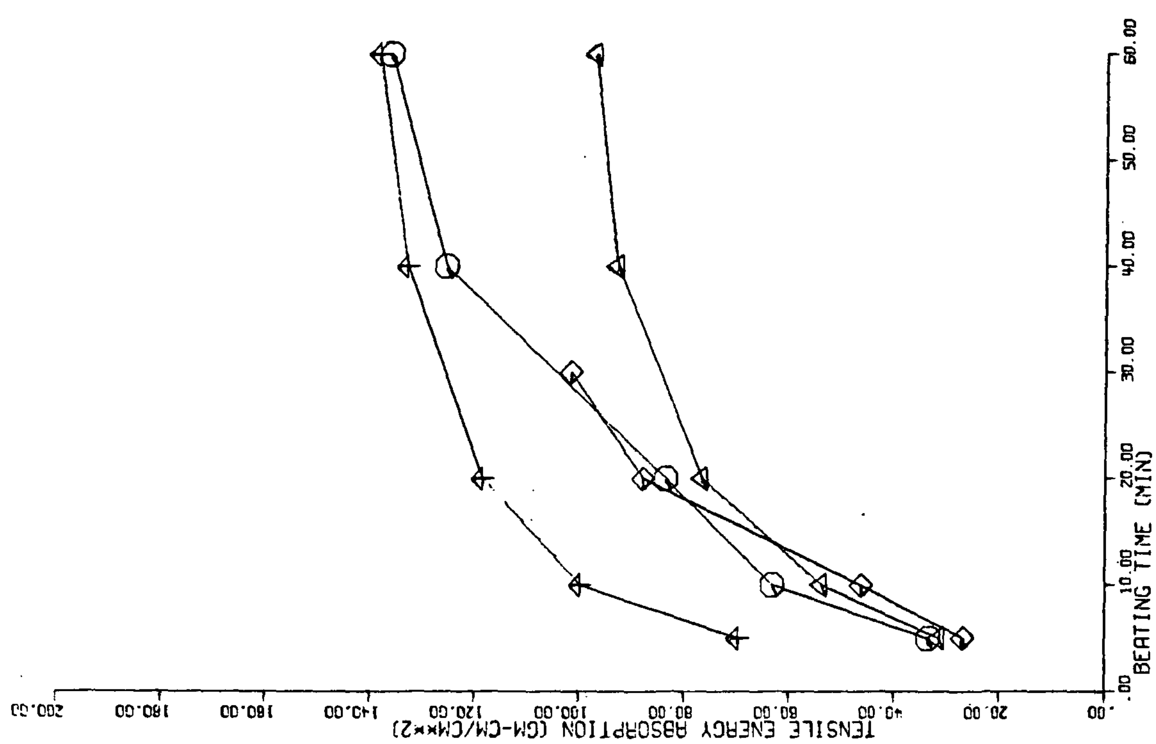


Figure 19. Tensile Energy Absorption Versus Beating Time

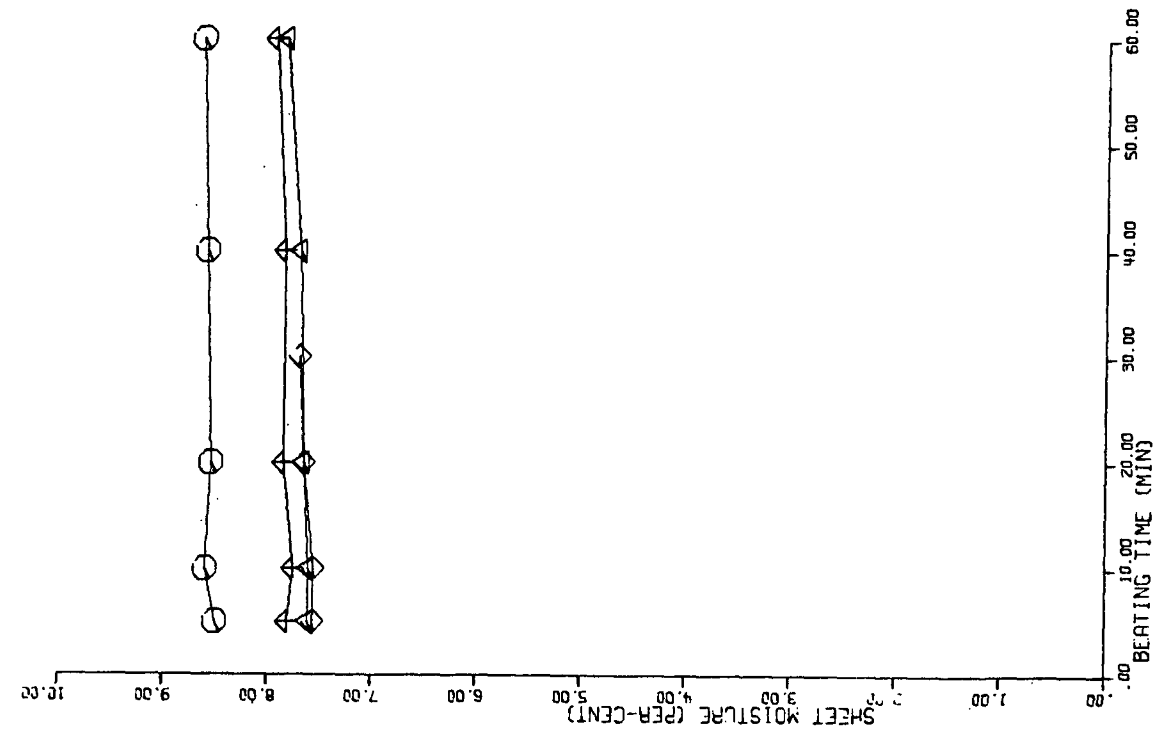


Figure 20. Moisture Content of Standard Handsheets

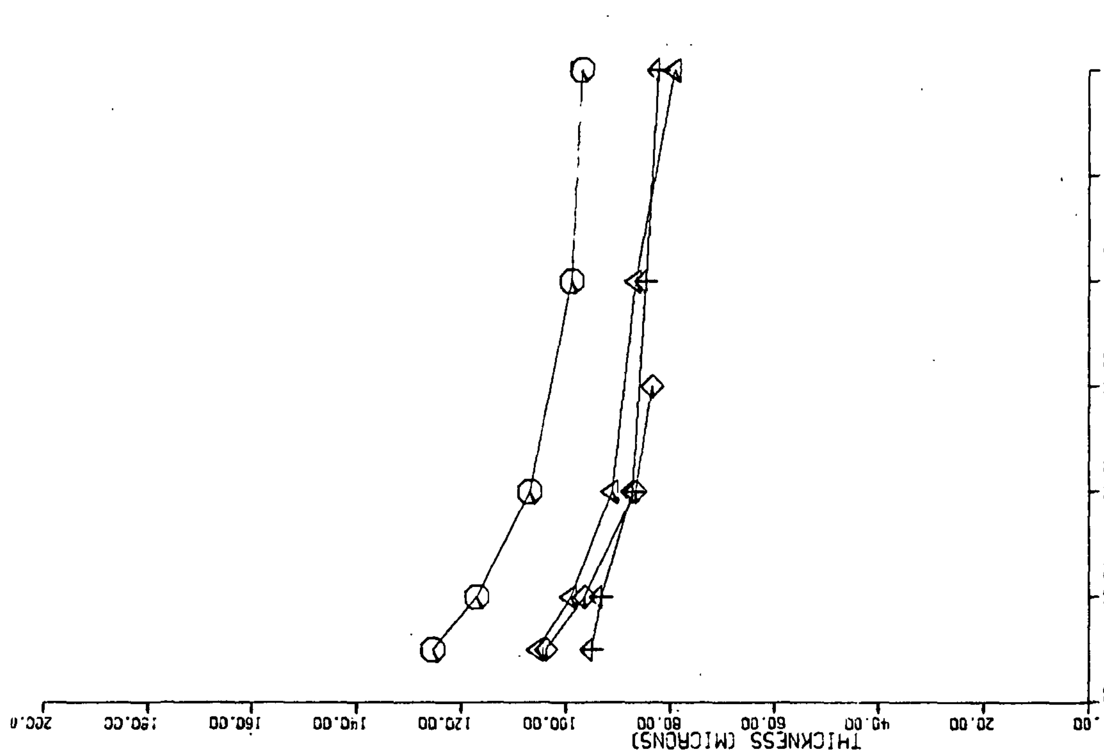


Figure 22. Thickness of British Standard Handsheets Versus Beating Time

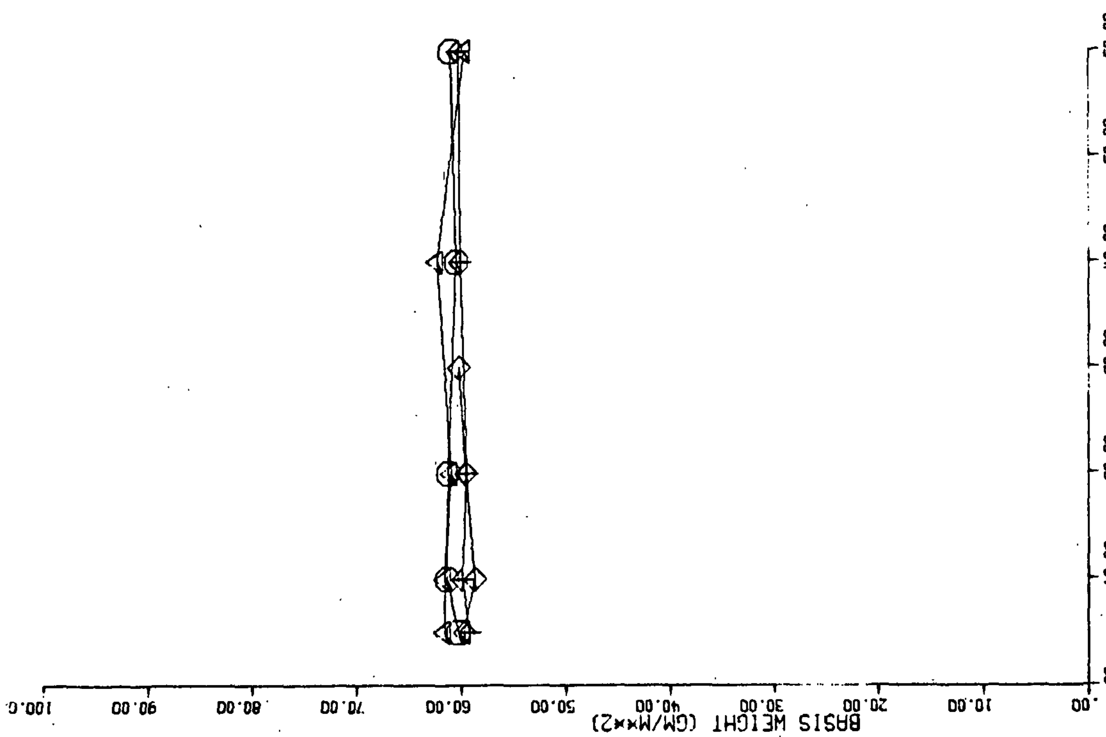


Figure 21. Basis Weight of Handsheets

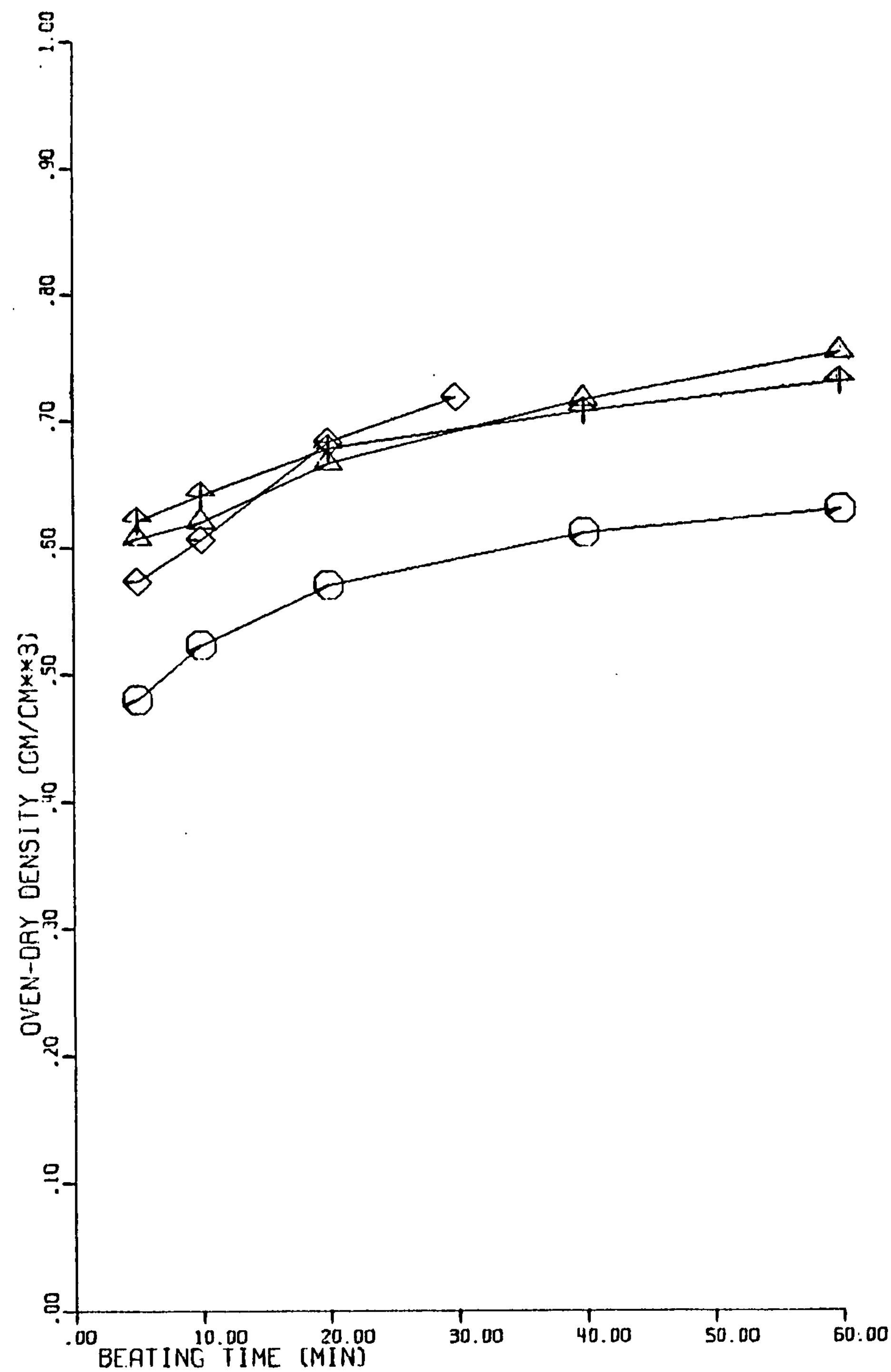


Figure 23. Ovendry Density of Standard Handsheets

TABLE II

SYMBOLS FOR SAMPLE IDENTIFICATION

Symbol	Letter	Number	Description
	A	1	Western softwood bleached sulfite
	B	2	Southern softwood unbleached kraft
	C	3	Northern hardwood bleached kraft
	D	4	Northern softwood bleached kraft

Some of the tests, such as the Bauer McNett analysis or the complete fiber length distribution, do not yield a single number. These results could not be plotted in the summary graphs but are discussed in the later sections of this report.

DRAINAGE PROPERTIES

The large increase in the filtration resistance and the corresponding drop in the Canadian and Schopper-Riegler freeness show clearly the large decrease in "drainability" of these pulps as they are beaten. There is quite a good correlation between the filtration resistance, at a pressure drop of 50 centimeters of water, and Canadian Standard freeness for all four of the stockpile pulps over the beating range employed. This relationship is shown in Fig. 24. This might not apply for pulps which were considerably easier to drain or for those which had been beaten far beyond this range. The increase in drainage resistance is almost completely due to the large increase in specific surface of these samples. This shows up in the fiber length distribution as an increase in the number of shorter fibers and fines and also in the actual measurement of the hydrodynamic specific surface by filtration analysis. The relative importance of specific surface and specific volume in determining the drainage resistance can be seen in Fig. 25 and 26. The specific volume has little effect on the filtration resistance, while the specific surface has an overpowering effect on the filtration resistance or freeness. The specific volume measures the swelling and fibrillation of the pulp, which in turn has an immediate positive influence on the bonding of the pulp fibers in the sheet. The fines and shorter fibers, on the contrary, increase the hydrodynamic surface and thus the filtration resistance, and produce a pulp which drains more slowly, but does not necessarily have an improved strength. It is important to be able to distinguish between these two characteristics, and it is possible, as in high-consistency refining, to process a pulp in such a way as to change primarily one characteristic, in this case specific volume, while having a small effect on the other. In the case of HCR one often obtains a strong sheet at freeness levels considerably above expectation because there is less unnecessary production of fine particles and increased hydrodynamic surface in this refining process.

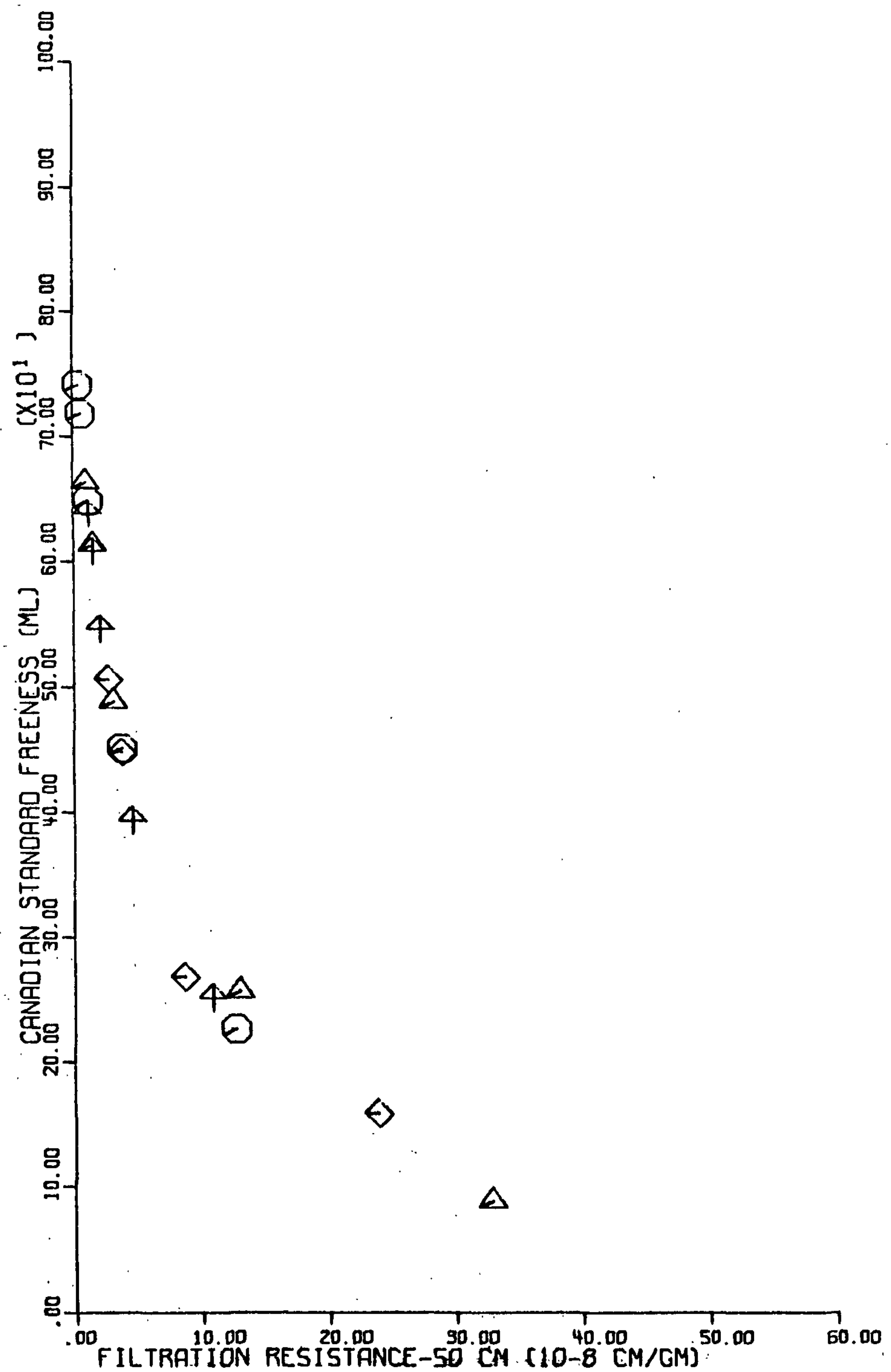


Figure 24. The Correlation Between Filtration Resistance and Canadian Standard Freeness

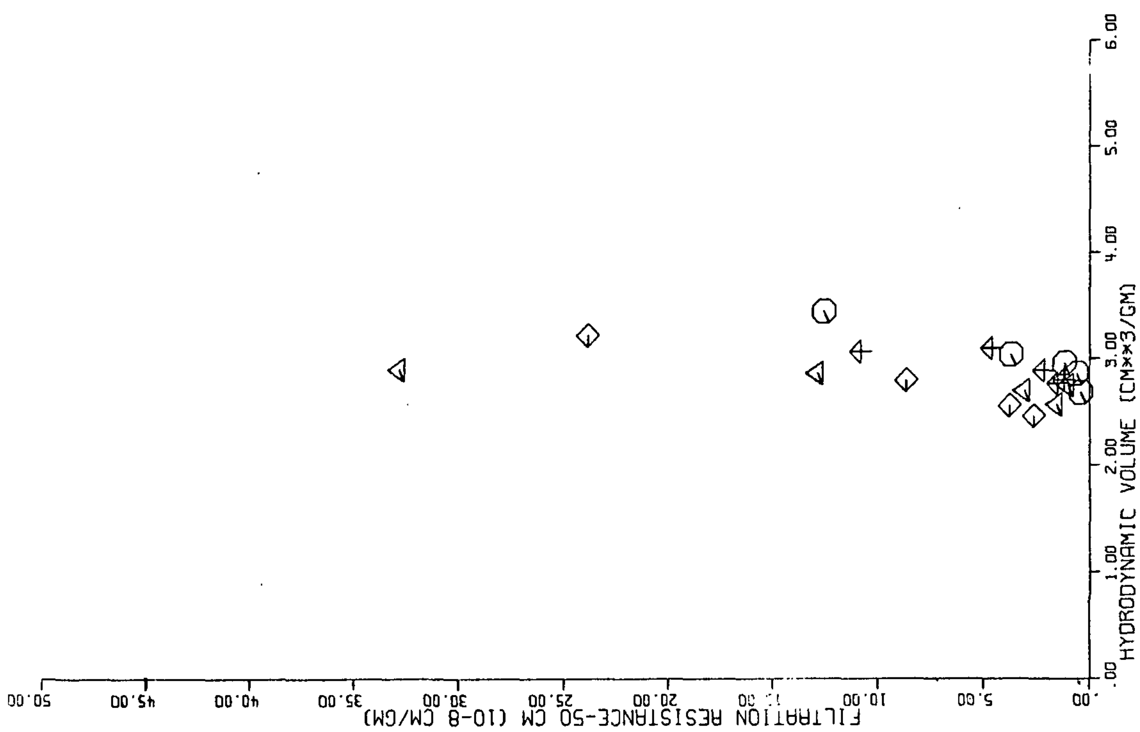


Figure 25. Scatter Diagram of Filtration Resistance and Hydrodynamic Volume

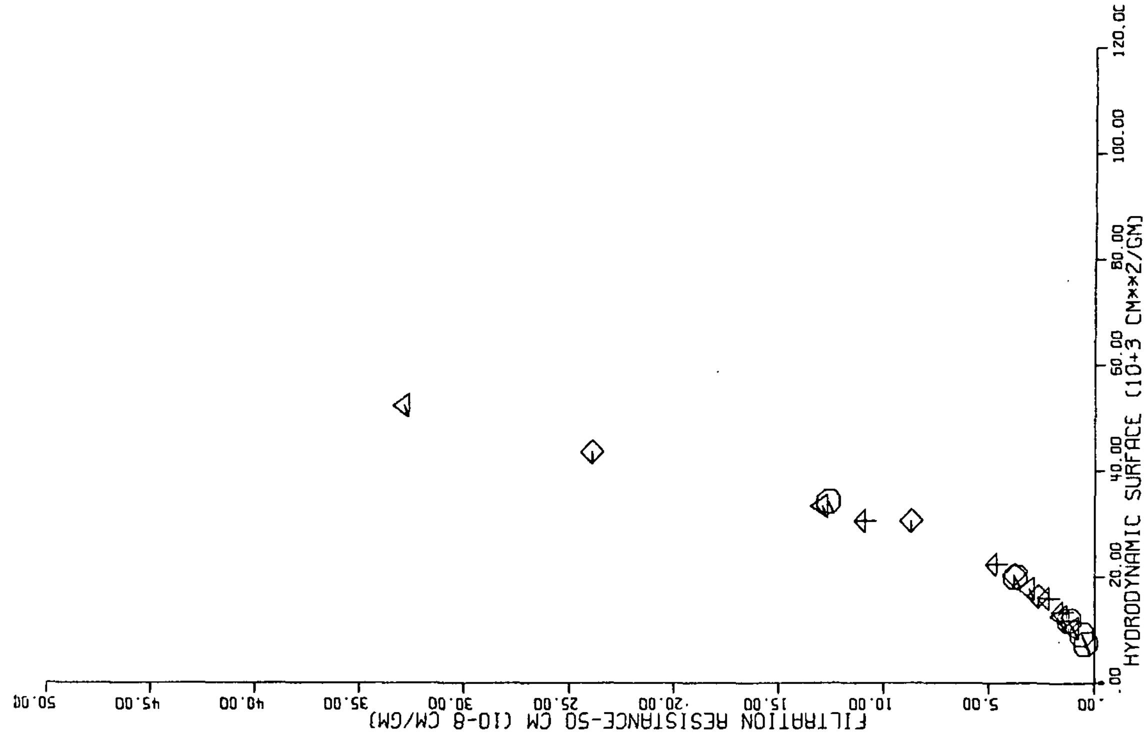


Figure 26. The Relationship Between Filtration Resistance and Hydrodynamic Surface

The separation of these two concepts of hydrodynamic surface and hydrodynamic volume should be a part of any attempt to interpret beating or refining of pulps. It might be interesting to see, for example, what the relative increases are in surface and volume for pulps beaten in refiners with sintered-metal tackle. Professor J. Chiaverina, University of Grenoble, France, has reported a 40% increase in burst at the same energy input or a 30% decrease in power requirement at the same value of burst factor for this type of refiner. These results were reported at the 11th Annual Pulp and Paper Conference, Western Michigan University, January 20, 1967. These refining methods show an indication of producing stronger paper more efficiently, and an analysis of the pulp characteristics would help one understand and control the process.

FIBER DIMENSIONS

The complete fiber length distributions for each of the beating intervals are presented in Appendix II. These graphs show the distribution of fiber length for each of the pulps at each of the beating intervals. The general effect of beating on fiber length distribution is summarized in Fig. 27-30, which compare the fiber length distribution for the last beating interval for each pulp with that for only five minutes of beating. These particular graphs give a qualitative indication of the resistance of each of the pulps to shortening or the generation of finer materials.

The Bauer McNett analyses for the same fiber or pulp sample are listed in Appendix III. Because of the lack of accuracy in measuring the consistency of these pulp samples, however, the most valid interpretation of these curves should be based perhaps only on the relative percent of material greater than 200 mesh and not too great a significance should be attached to the apparent percent of fines, which was calculated by difference. Since there were some untraced difficulties in the apparatus or procedures, average values were not computed, and the raw data are presented.

For four samples covering a rather wide range in pulp properties and beating intervals the grid-count fiber length was also measured and a comparison of the grid-count number-average fiber length and number-average fiber length calculated from the projection results is shown in Table III. These results show clearly the great difference in fiber length distribution for these samples. The large proportion of long fibers in the southern-pine kraft and the western softwood is in contrast to the large proportion of shorter fibers in the hardwood sample. The "cutting" behavior of these particular pulps, as shown in Fig. 27-30, is also

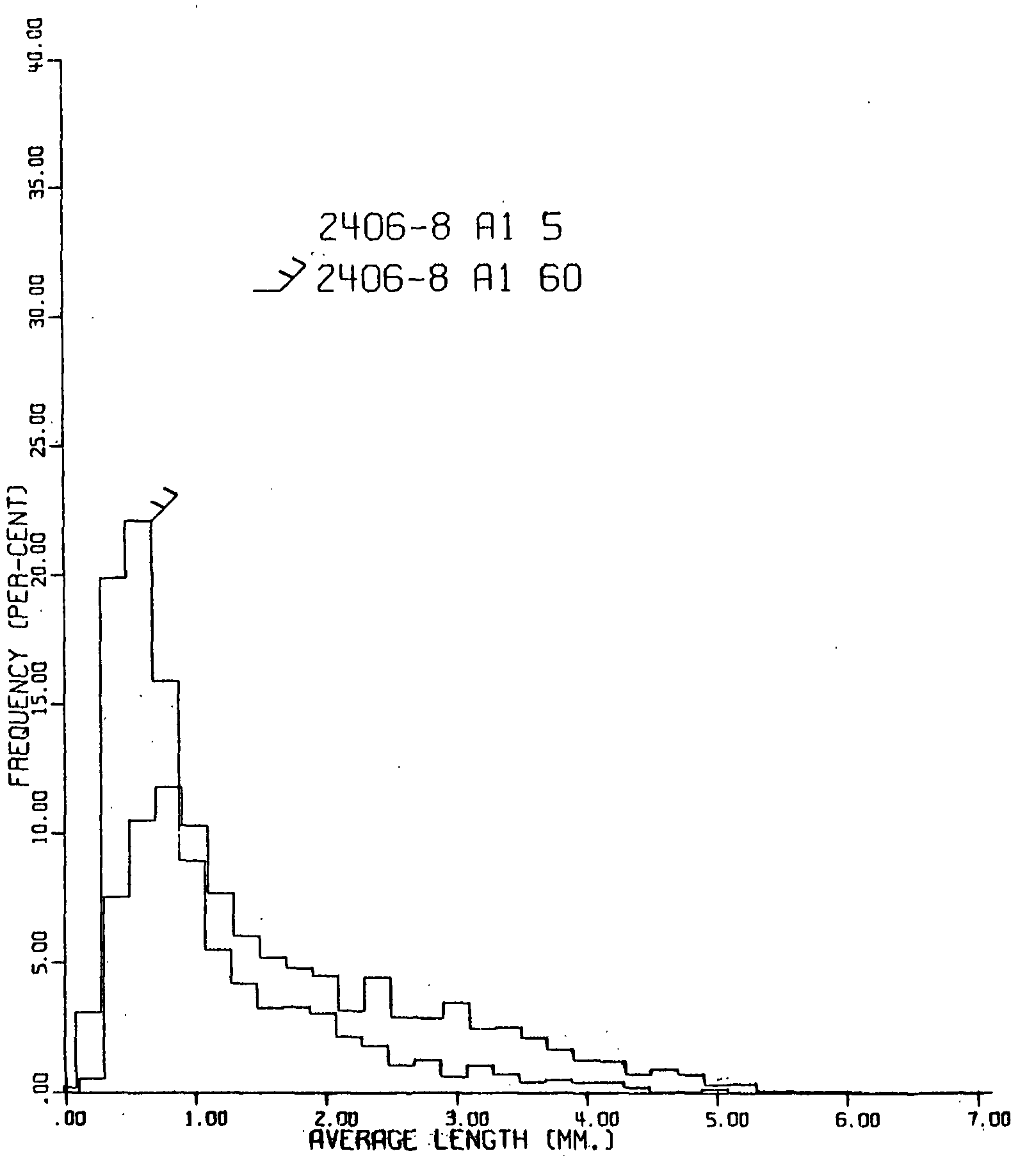


Figure 27. Fiber Length Distributions for Bleached Western Softwood Sulfite at 5 and 60 Minutes Beating

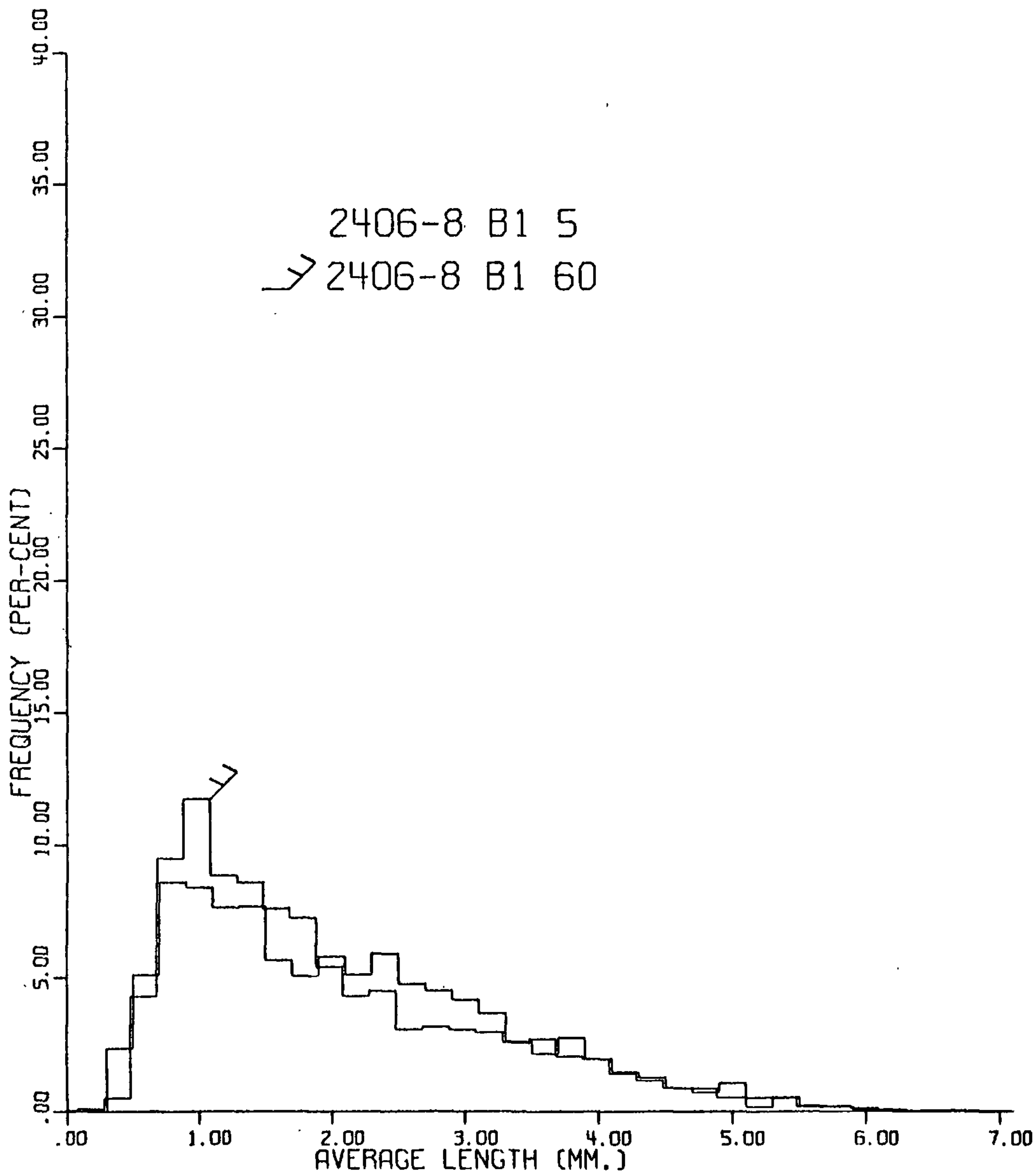


Figure 28. Fiber Length Distributions for Unbleached Southern Pine Kraft at 5 and 60 Minutes of Beating

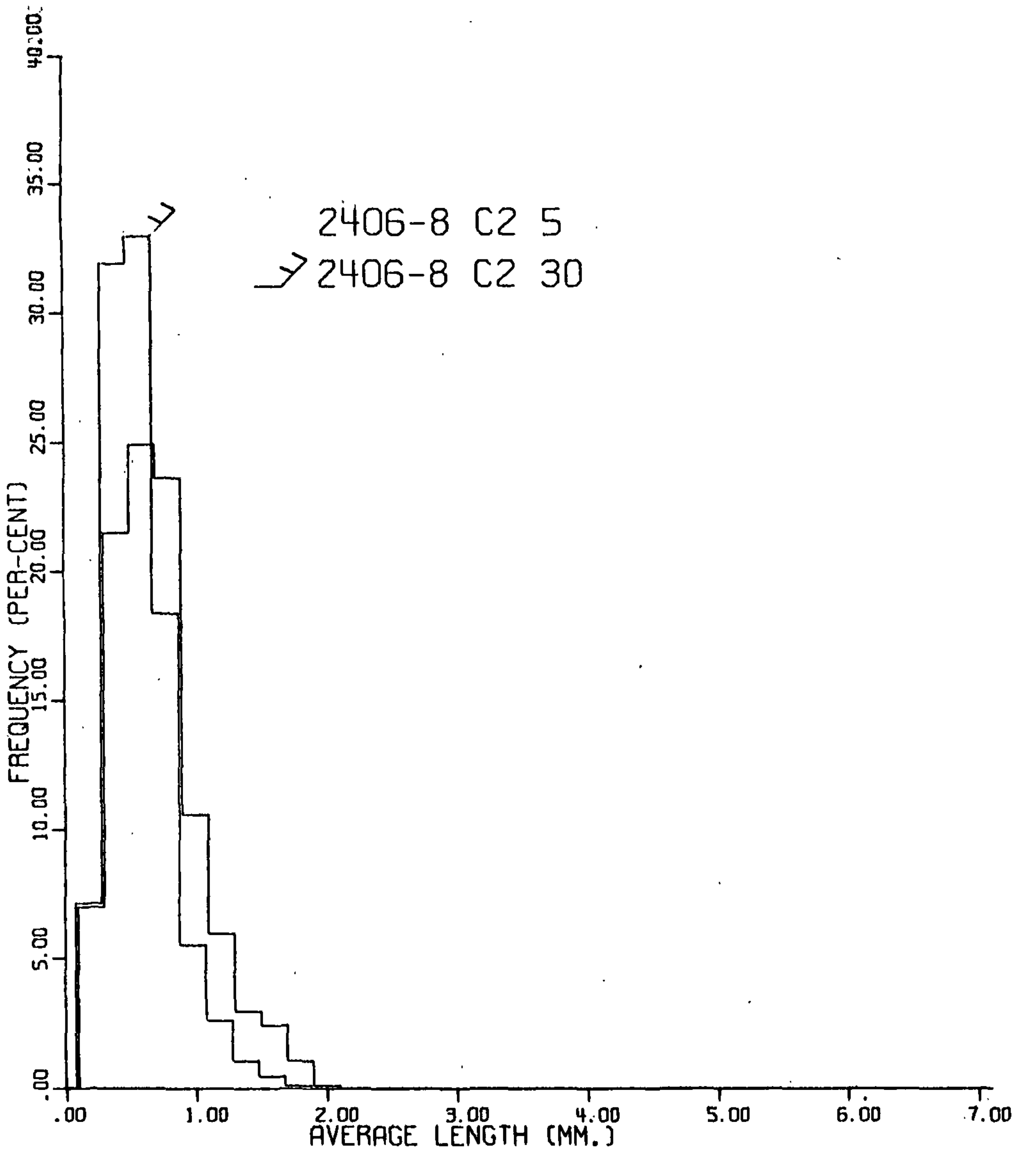


Figure 29. Fiber Length Distributions for Bleached Northern Hardwood Kraft at 5 and 30 Minutes of Beating

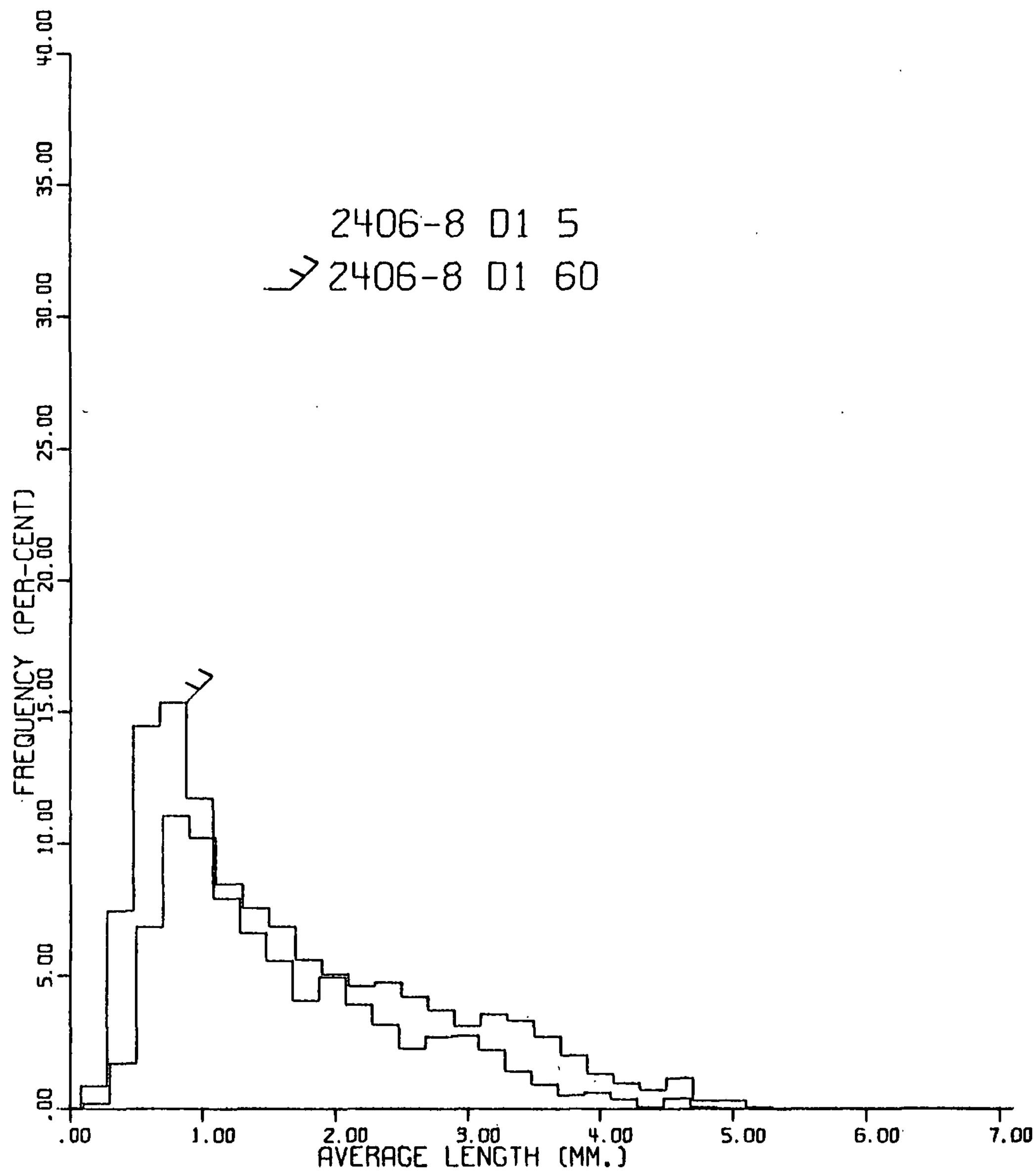


Figure 30. Fiber Length Distributions for Bleached Northern Softwood Kraft at 5 and 60 Minutes of Beating

interesting in that certain pulps show a much greater tendency than others to have their fiber length reduced by the Valley beater. The one case being most marked is that of Sample A which can be seen from Fig. 27 to cut very readily and to yield a high proportion of material of fiber length less than 1 millimeter. Other pulps, such as B or D, cut much less severely and tend to retain their fiber length for much longer periods in the Valley beater.

TABLE III

COMPARISON OF FIBER LENGTH MEASUREMENTS

Average Fiber Length, millimeters	Grid Count	Projection, number average
C05-1	0.60[a]	--
C05-2	0.78	--
C05 (av.)	0.69	0.71
C30-1	0.77	--
C30-2	0.71	--
C30 (av.)	0.74	0.59
D05-1	1.71	--
D05-2	1.76	--
D05 (av.)	1.74	1.89
D60-1	1.72	--
D60-2	1.38	--
D60 (av.)	1.55	1.41

[a] Average of four counts, 250 to 800 fibers per count.

Another significant factor in characterizing fiber dimensions is the coarseness, or average weight per unit length of fiber. The measured coarseness for the unbeaten pulps is shown in Table IV. The apparent values of coarseness for pulps with mixed species, such as the unbleached southern pine (B) and the mixed northern hardwood (C), represent an average coarseness which is a function of both the coarseness of the individual species and the percentage mix of species in the pulp. Such averages should be used in only a qualitative manner.

TABLE IV

COARSENESS OF STOCKPILE PULPS

Pulp	Coarseness, mg./100 m. Max.	Min.	Av.[a]
A-00	30.4	25.1	28.3
B-00	57.1	50.6	53.1
C-00	19.9	17.5	18.3
D-00	31.0	29.5	30.2

[a] Of 4 determinations.

The large differences in the coarseness of these samples are still evident, however, from the data; and these differences may help to explain some of the differences in the mechanical properties of sheets made from these pulps.

A few preliminary measurements of coarseness on the beaten samples showed that the coarseness of the softwood bleached sulfite (A) stayed practically constant for at least fifty minutes in the Valley beater. The apparent coarseness of Pulps B and C decreased somewhat, and the measured coarseness of Pulp D decreased very strongly. Further measurements would be needed to check these results and see if this is a real, reproducible effect which can help our understanding of the beating and refining behavior of these pulps. The preliminary data showed 20 to 30% decrease in apparent coarseness for Pulps B and C, and a 50% decrease for Pulp D. This is a large change which does not seem to be corroborated by any parallel change in the fiber length distributions or the handsheet properties, so these initial figures should be used with caution until verified by further work.

FIBER STRENGTH

The zero-span tensile test has been shown by previous work to be a reliable and relatively direct measure of the intrinsic fiber strength. The zero-span tensile results as a function of beating time are shown in Fig. 9. The actual level and the trends of this test can be seen by inspection of that graph. To be noted especially are the increases in zero-span breaking strength as a function of beating time. It was thought for some time that this apparent increase in zero-span breaking length as a function of beating time was due simply to better bonding of the fibers and was not actually an increase in fiber strength. Recent results to be reported elsewhere on Project 2406 have shown that there is an actual and real increase in the strength of individual fibers as they are beaten. Further information on the z-tensile test and its comparison with the individual fiber tests can be found in Reports One and Three; the effect of beating is shown in Report Five, Project 2406.

BONDING

Three measures of bonding were obtained in this study. The first of these, scattering coefficient, has been used frequently in the past to measure the relative level of bonded area in a sheet. The second method, that of dynamic gas adsorption, is a measure of the unbonded area available to adsorption by nitrogen gas at very low temperatures. This dynamic procedure, which was originally proposed by Stone and Scallon as a convenient replacement for the laborious gas adsorption method used by Haselton, was further developed under an Institute project and has been used in this study to measure the unbonded area of the handsheets.

Unbonded, water-dried fibers from the same beaten pulps were produced by taking a small amount of well-dispersed fiber, drying it on the Institute web-former, and carefully doctoring it off the barely warm first yankee cylinder. The fibers were in a very dilute, closed, recirculating system so that most of the fines and finer particles were also collected with the fibers. The final collection of dried fibers has a very small proportion of fibers bonded to each other. This tow of unbonded water-dried fibers was then tested for its surface area in the same manner as the handsheets. The difference of these two data gives a reasonable indication of the bonded area in the handsheets.

A third measure of bonding was the perpendicular (_z_) tensile test which is a measure of the force necessary to separate the sheet along a region parallel to its surfaces. This test has been subjected to further investigation under a different project and the results of the test evaluations were reported at the 1967 TAPPI meeting in New York.

Figure 31 shows the well-known relationship between scattering coefficient and the unbonded area of the handsheets. For the four widely different pulps,

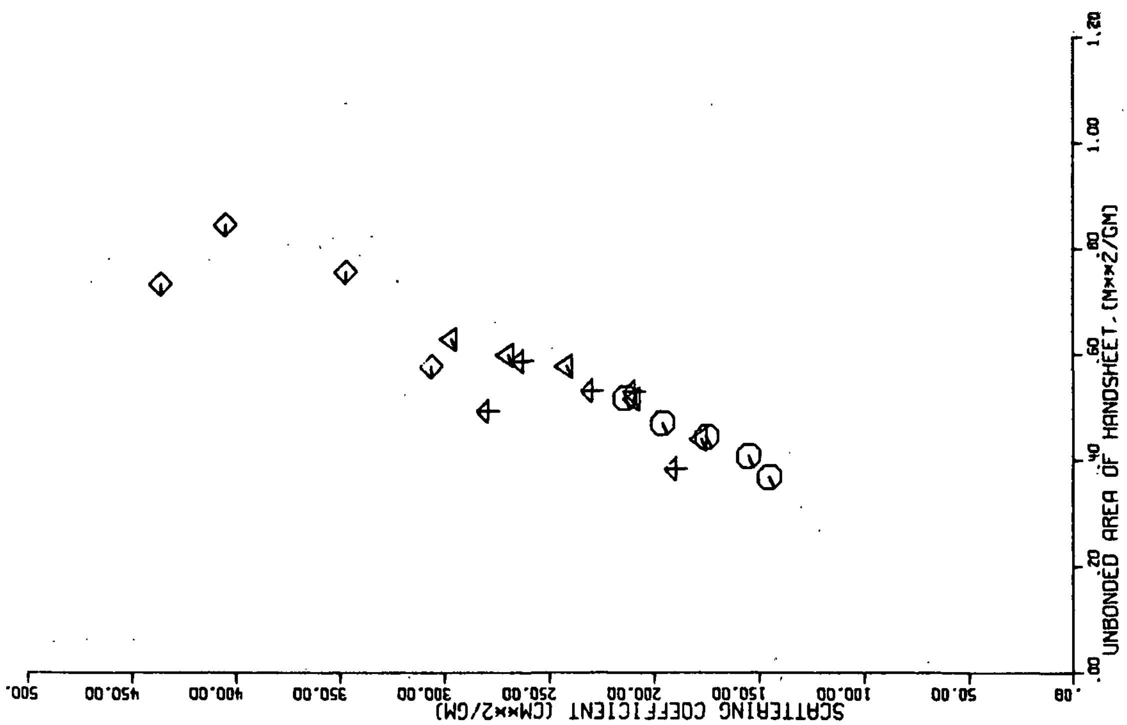


Figure 31. Increase in Optical Scattering Coefficient with Unbonded Area

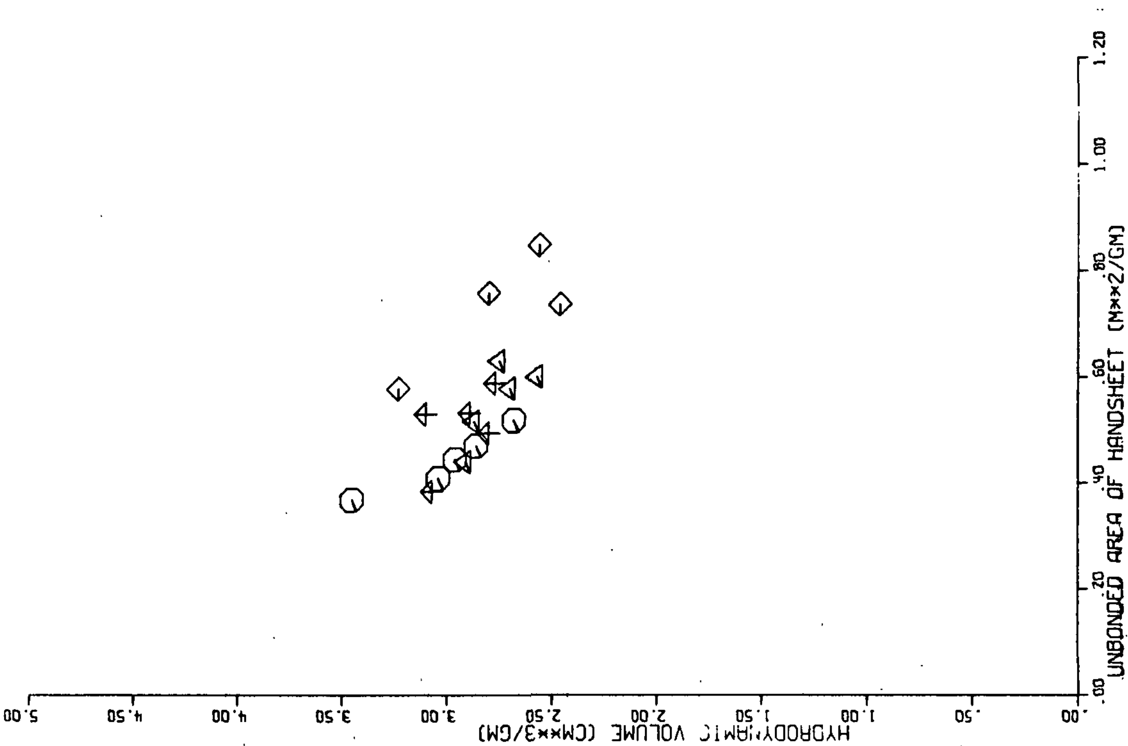


Figure 32. Effect of Hydrodynamic Volume on Unbonded Area

the data points seem to fall within a common range but there is no unique curve common to all four pulps. There was no evident correlation between the area of unbonded fibers or the hydrodynamic surface and the scattering coefficient of the dried handsheet.

Figure 32 shows a distinct decrease in the unbonded area of a handsheet with an increase in hydrodynamic volume. This is as would be expected since the increase in hydrodynamic volume would indicate a more deformable, more easily bonded pulp and, when formed into a sheet and dried, this same sample would yield a lower unbonded area. The scatter diagrams of hydrodynamic surface and the area of the unbonded water-dried fibers versus the unbonded area of the handsheets as measured by gas adsorption did not show any evident correlation.

The relationship between surface area of the unbonded water-dried fibers and the hydrodynamic surface area as measured by filtration resistance is shown in Fig. 33. The large increase in hydrodynamic surface with only a small increase in the area of the unbonded fibers can be rationalized by considering either the loss of fines in the web-former procedure, the attachment of these fines and subsequent drying on the parent fibers, or the collapse of fibrillar material and its adhesion to the water-dried fibers. It is likely that, in some measure, all three of these phenomena occur. Two pulps, however, which seem to show somewhat differing behavior are the unbleached southern pine kraft (B) and the northern pine bleached kraft (D). The northern pine material (D) tends to retain a larger amount of its unbonded area when it is dried.

One would expect that the z-tensile test value would increase as the unbonded area of the handsheet decreases. For any one pulp there is a trend but each pulp is at a different level, as shown in Fig. 34. The theory of the z-tensile

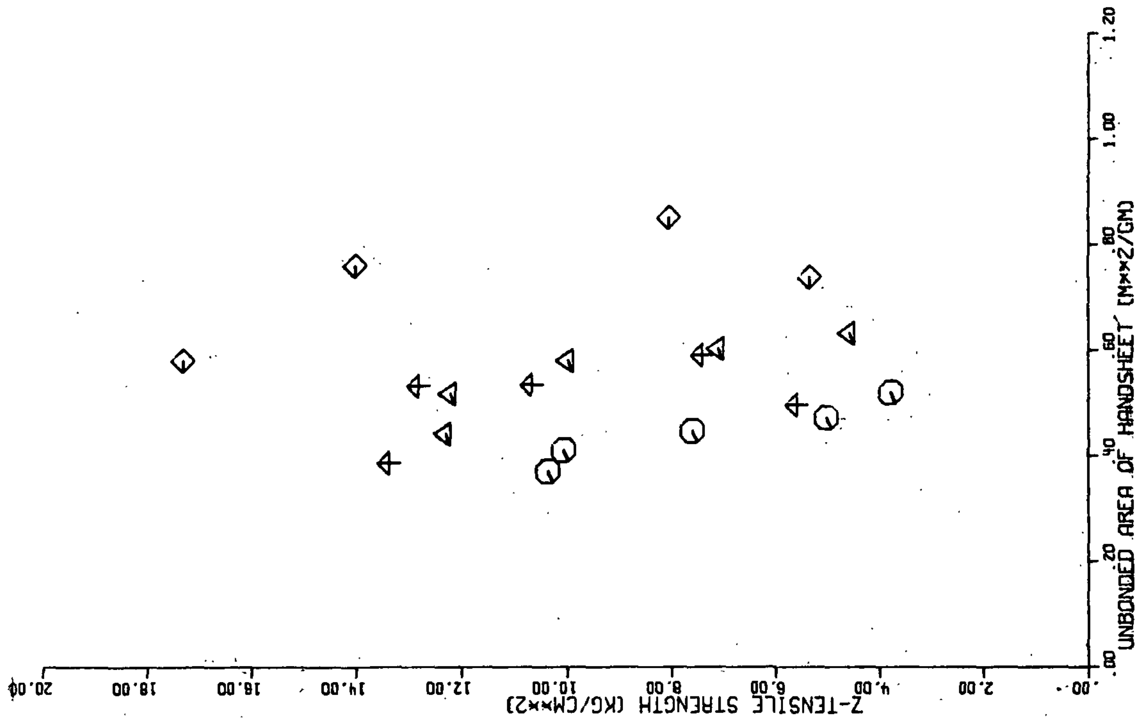


Figure 34. Scatter Diagram of Perpendicular ($\underline{z}$) Tensile and Unbonded Area

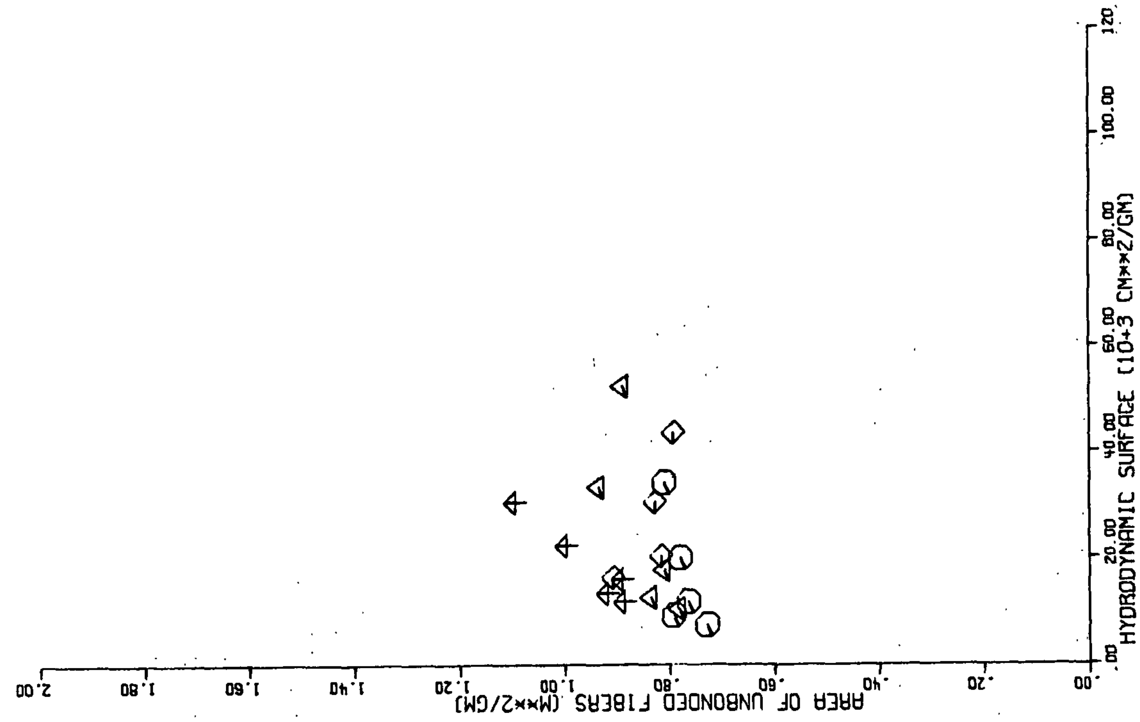


Figure 33. Scatter Diagram of Hydrodynamic Surface and Area of Unbonded, Water-Dried Fibers

test and the most recent developments in its use were discussed by Wilmer Wink at the 1967 TAPPI meeting. In quoting an abstract from Mr. Wink's paper, "One can safely infer that microscopic stress concentration is an inherent effect in all current bonding strength test procedures." These stress concentration effects make it very difficult, if not impossible, to measure the absolute bonding strength of a given interfiber bond and the final result depends very strongly upon the homogeneity or formation of the sheet and on other physical factors in the test. Figure 35 does, however, show a general increase in the z-tensile test as a function of hydrodynamic volume; this again is an indication of the greater wet conformability of the fibers and their ability to conform to one another and thus bond. A further discussion of bonding as measured by these various methods and their relationship to empirical tests such as tensile, burst, and tear are included in one of the sections to follow.

Table V shows the absolute bonded area of each of the samples calculated from the unbonded area of the handsheet and the area of the water-dried fibers.

The values for relative bonded area for the hardwood pulp (C) are obviously too low. This is attributable to the loss of the very small hardwood fibers and particles in the fiber-drying procedure. An approximate calculation of the error to be expected from the loss of fines in the fiber-drying procedure showed that the error was always negative, and its magnitude increased from a value approximately proportional to the percent loss, to a value of 100 percent error when half of the potential dry-fiber area was lost in the web-former drying process. That is, the relative bonded area calculated from the above data is probably somewhat less than the actual relative bonded area for the long-fibered pulps and is considerably less than the actual value for the very short-fibered hardwood pulp. The expected error for a handsheet with a true bonded area of 50% was calculated to be -1% for 1% fiber

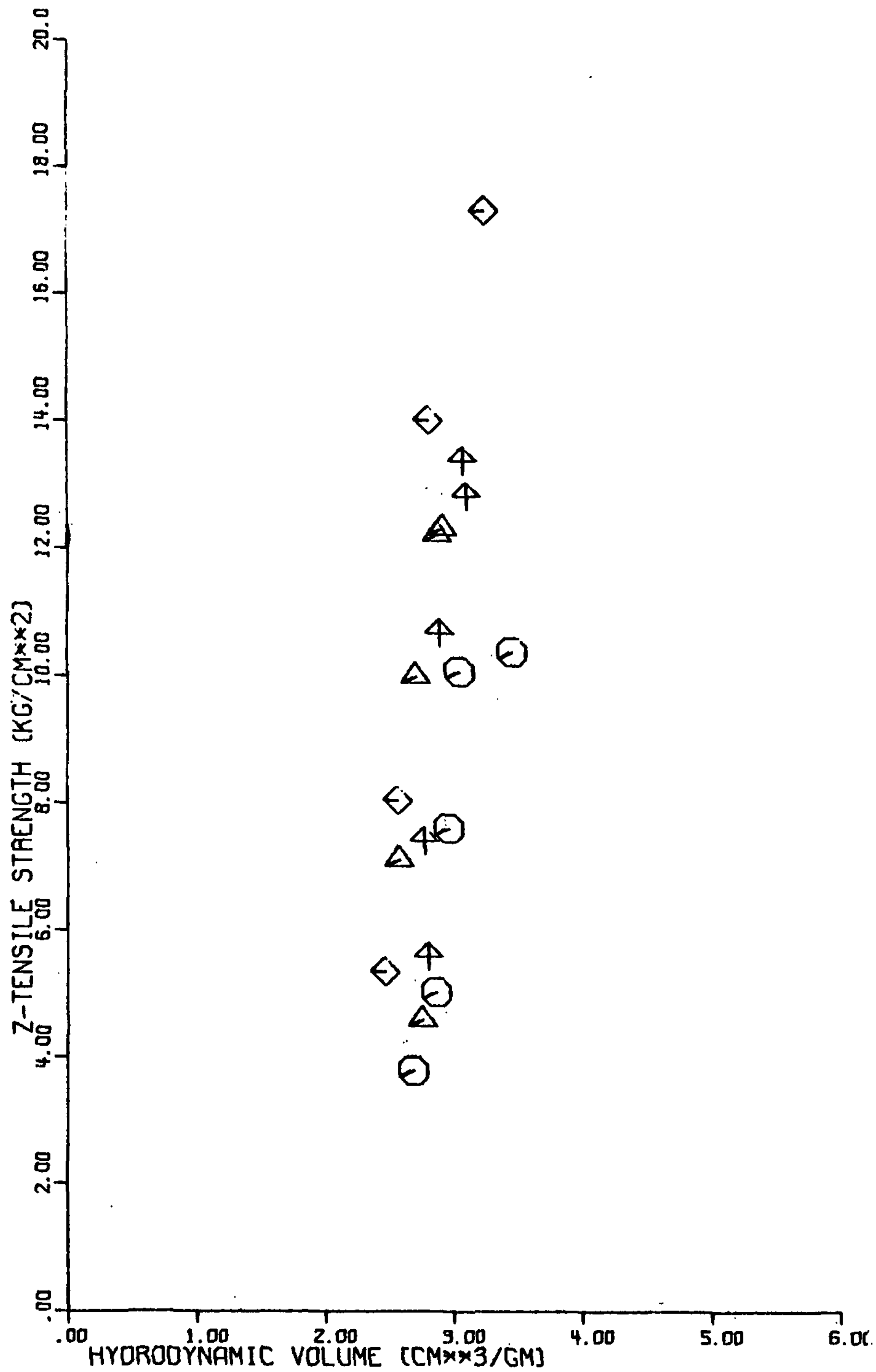


Figure 35. Effect of Hydrodynamic Volume on the (z) Tensile Test

loss, -11% for 10% fiber loss, and -100% for 50% fiber loss. That is, if half the fiber area is lost in forming the unbonded, water-dried fibers and none is lost in forming the handsheets, the calculated bonded area will be zero. This apparently happened for one of the hardwood pulps.

TABLE V

ABSOLUTE AND RELATIVE BONDED AREAS

Sample	Unbonded Area of Handsheet, $m.^2/g.$	Unbonded Area of Fiber, $m.^2/g.$	Absolute Bonded Area, $m.^2/g.$	Relative Bonded Area, %
A05	0.632	0.781	0.149	19
A10	0.601	0.836	0.235	28
A20	0.580	0.809	0.229	28
A40	0.518	0.935	0.417	45
A60	0.441	0.889	0.448	50
B05	0.519	0.728	0.209	29
B10	0.471	0.791	0.320	40
B20	0.445	0.763	0.318	42
B40	0.410	0.779	0.369	47
B60	0.370	0.810	0.440	54
C05	0.737	0.907	0.170	19
C10	(0.850)	0.816	--	--
C20	0.760	0.827	0.067	8
C30	0.580	0.792	0.212	27
D05	0.496	0.886	0.390	44
D10	0.590	0.918	0.328	36
D20	0.534	0.889	0.355	40
D40	0.532	0.995	0.463	47
D60	0.385	1.093	0.708	65

Certain improvements could be made in the fiber drying procedure to decrease the possibility of loss of fines, but such changes would require major changes in the present web-former or the construction of a separate apparatus.

At the present time, it appears that the use of the web-former to produce unbonded, water-dried fibers is most useful for long-fibered, moderately beaten pulps and it should be used with caution on any pulp which has a large proportion of small fibers or fines.

RELATIONSHIP OF MECHANICAL PROPERTIES OF HANDSHEETS TO PULP CHARACTERISTICS

This section treats the influence of the pulp characteristics of fiber length, fiber strength, bonding, and drainage properties on the dependent properties of tensile strength, burst factor, tear factor, and in-plane tear energy. The first three of these tests are well known. The fourth, the Institute in-plane tear energy, is a newer test which is described below in the section on the effect of fiber length. For purposes of illustration, it was necessary to choose one test out of each of the pulp-characteristic groupings. The tests which were chosen to give a valid indication of each of these characteristics were as follows: fiber length, the weighted-average fiber length calculated from the fiber-length distribution; fiber strength, the zero-span tensile test; bonding, the unbonded area of the handsheet as measured by dynamic gas adsorption; and drainage, the filtration resistance measured on the research-model filtration resistance apparatus. In some cases, such as fiber strength measured by zero-span, the techniques have been developed by hard work over the years to a point where they are immediately useful. Other methods are less well-developed and obviously in need of further work.

THE EFFECT OF FIBER LENGTH

The effect of fiber length on the dependent physical properties of the handsheets is shown in Fig. 36-39. The scattered data on Fig. 36 and 37 show that other factors than fiber length are more important in determining the level of breaking length and burst factor. The next two figures show very clearly, however, the strong influence of fiber length on both the standard Elmendorf tear factor and the newer in-plane tear-energy test. Since the Institute in-plane tear test may not be familiar, the following comments have been added.

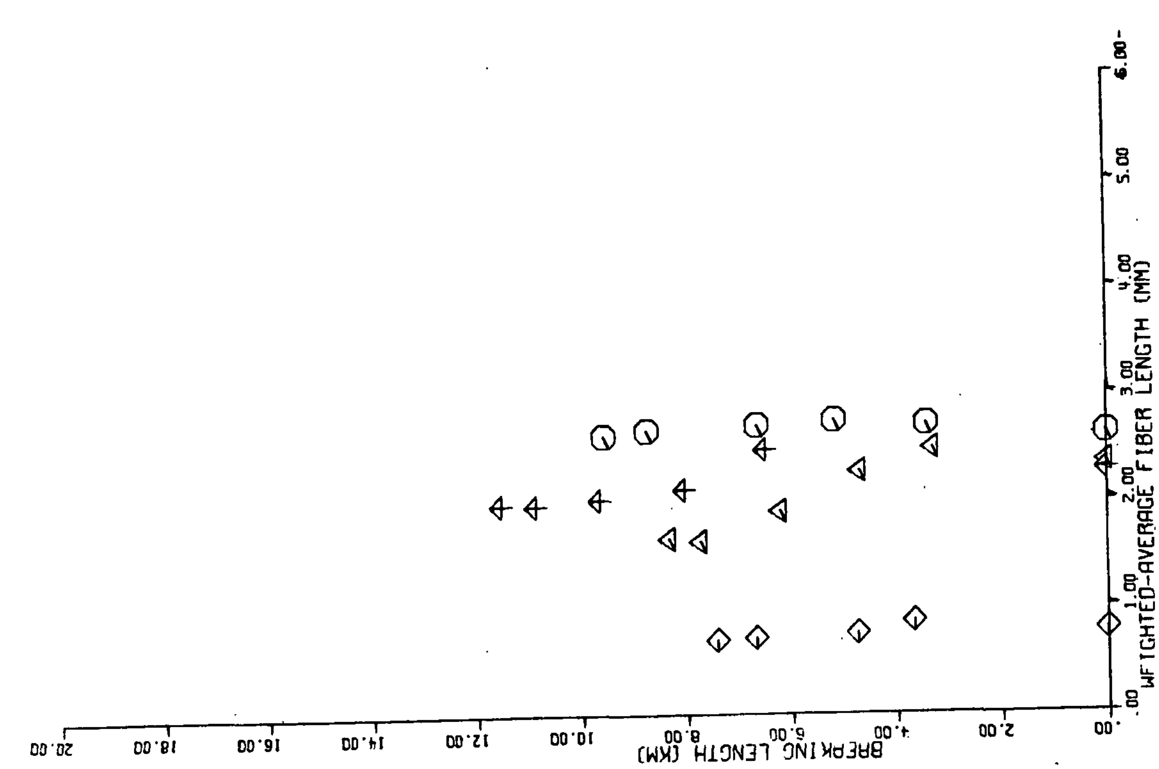


Figure 36. Scatter Diagram of Breaking Length and Fiber Length

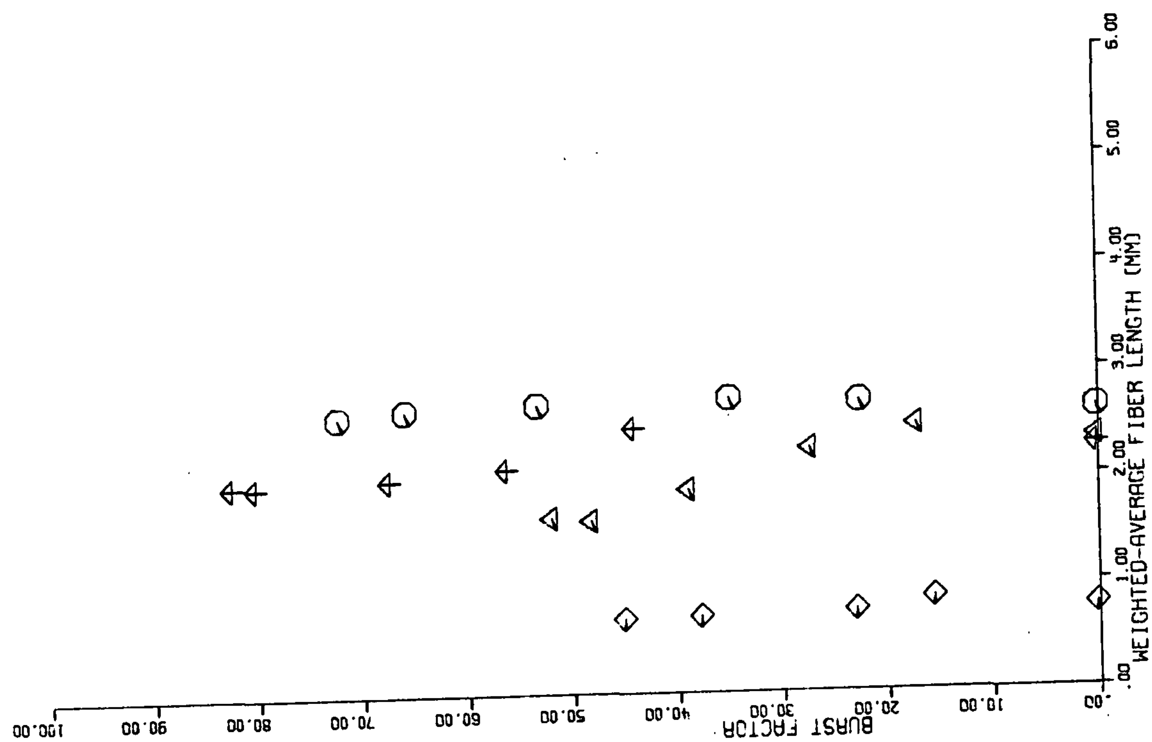


Figure 37. Scatter Diagram of Burst Factor and Fiber Length

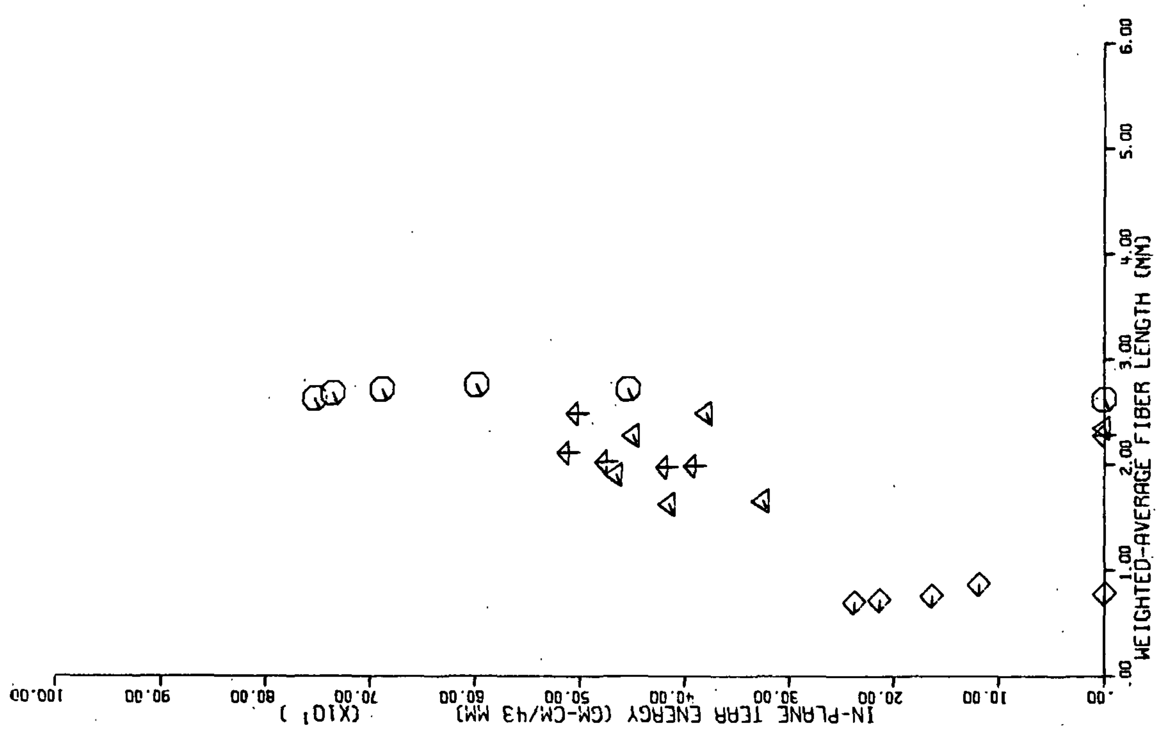


Figure 39. Effect of Fiber Length on the In-Plane Tear Energy

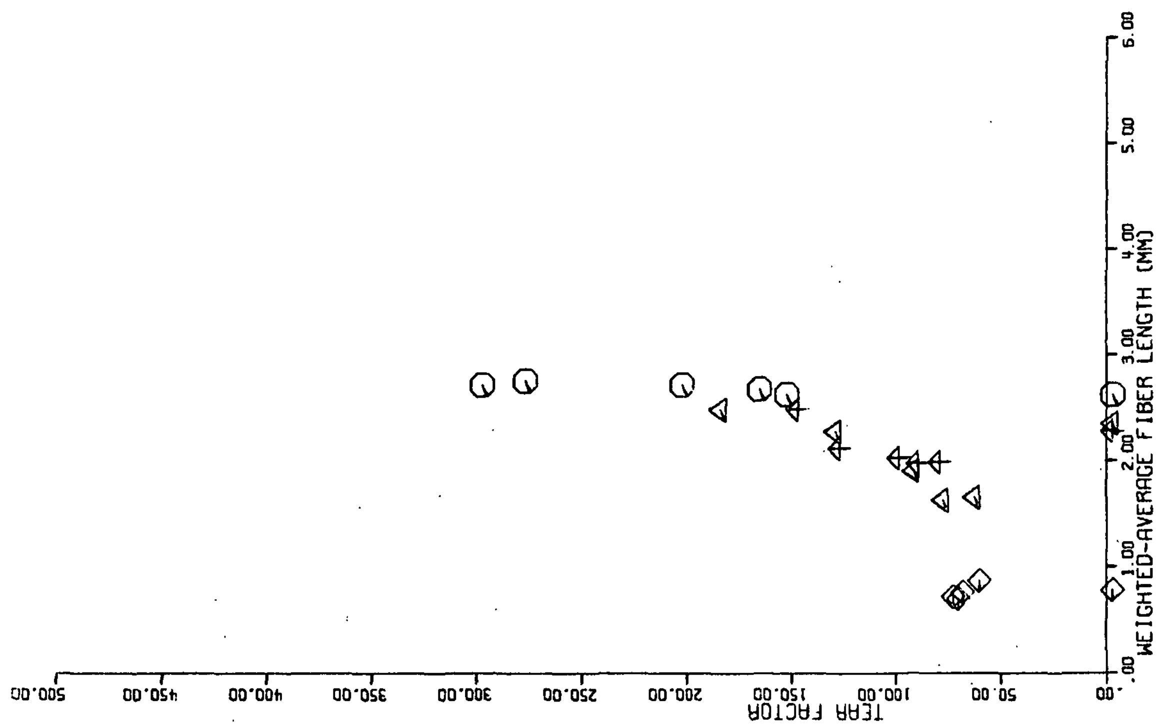


Figure 38. Effect of Fiber Length on the Elmendorf Tear Factor

There are two basic ways, or modes, in which a sheet can be torn. If one takes a sheet of paper and starts a small tear in it, he can continue the tear by two methods. The first way would be to move his hands perpendicular to the sheet of paper and simultaneously bend, and tear the sheet into two pieces. This is the mechanical mode of action which is used in the Elmendorf tear tester. The alternate mode of tearing, the in-plane mode, can be illustrated by our subject moving his hands apart parallel to, or in the same plane, as the sheet. This mode of tear can also be demonstrated by tearing the sheet while it is lying flat on a desk top. Now if we consider the immediate zone of the tear we can see that the two processes are mechanically quite different. The perpendicular tearing mode introduces considerable bending and peeling action in the immediate region of the tear, while the action in the in-plane tearing zone is mainly one of direct progressive tension. Which test is the most useful or pertinent to a given end-use evaluation would, of course, depend on which mode of tearing was most common in actual failure or use. The progressive failure of a bag in a drop-test, for example, might be much closer in the in-plane mode of tear than the perpendicular mode.

The in-plane tear energy was determined on an Instron tensile tester using a special set of skewed jaws. A more convenient device designed specifically for this test is under development.

Figure 40 shows the zero-span breaking length as a function of the fiber length. This was included as a test to see whether the fibers contained in the hardwood sample were short enough to markedly influence the measurement of zero-span breaking length. It is evident that the fibers were not so short as to give a spuriously low value.

Figure 41 is a cross-plot of the Elmendorf tear factor and the Institute in-plane tear energy. There seems to be no direct, consistent correlation between

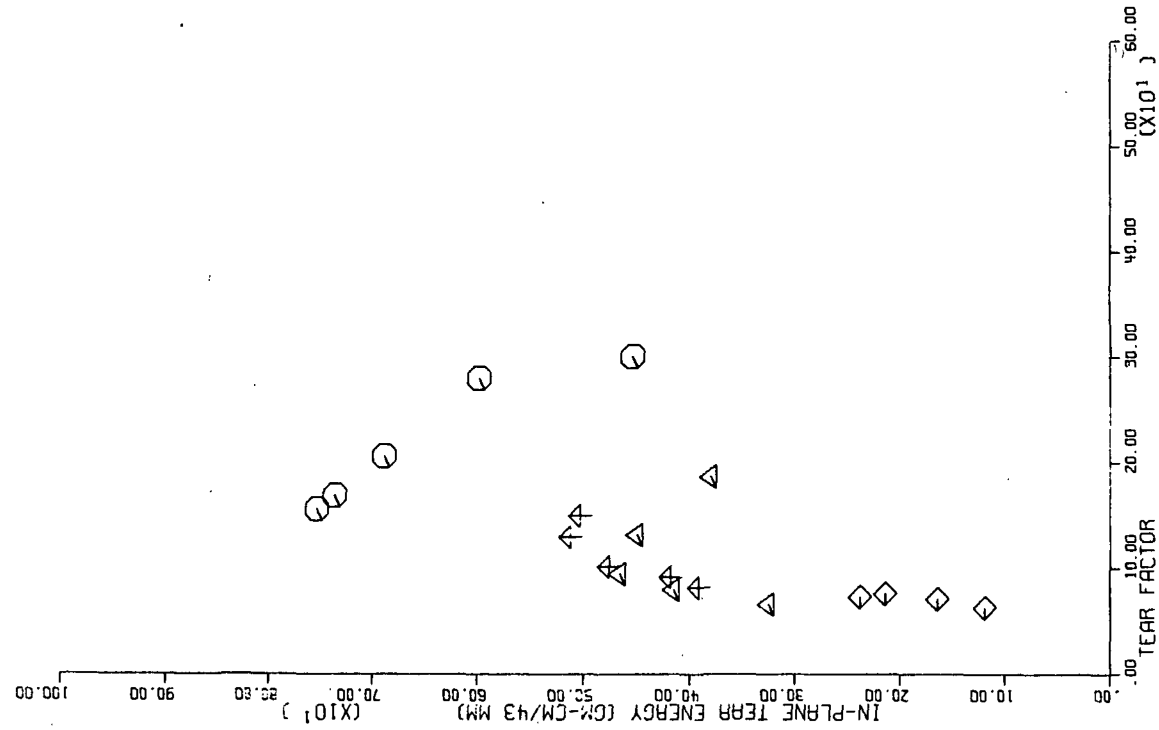


Figure 41. Scatter Diagram of Tear Factor and In-Plane Tear Energy

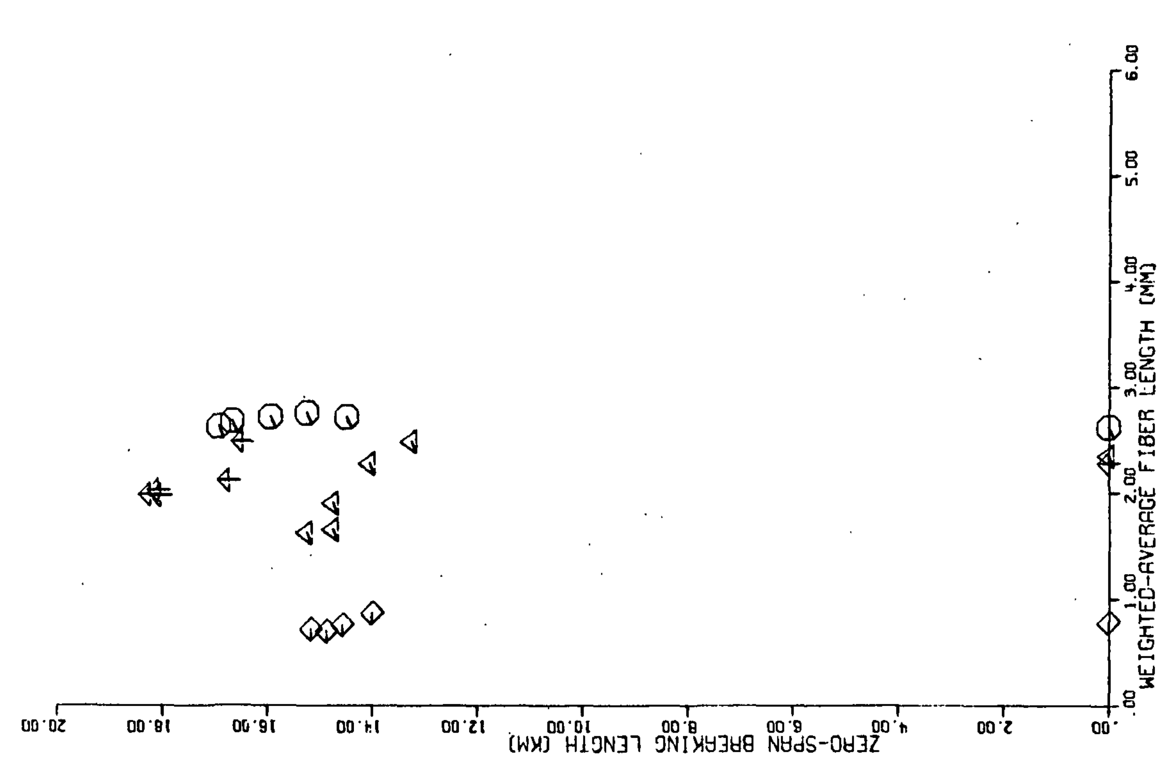


Figure 40. Check of the Influence of Average Fiber Length on Zero-Span Tensile Strength

the two tests. This is not, however, surprising since the mechanism of tearing is different in the two tests. The true value of either test and its useful correlation with end-use performance would depend on which mode of tear were most common for a specific application. In either mode of tear, however, the length of the fibers has a very strong influence on the final result as shown in Fig. 38-39.

THE EFFECT OF FIBER STRENGTH

The influence of the intrinsic fiber strength is clearly shown in Fig. 42-45 which give the breaking length, burst, tear factor, and in-plane tear energy as a function of zero-span breaking length. The strong and consistent increases in breaking length and burst factor with intrinsic fiber strength are clearly shown in the first two graphs. Figure 44 shows that if any correlation exists for tear it is perhaps negative; that is, as the intrinsic fiber strength increases, the Elmendorf tear factor decreases. Figure 45 shows that the in-plane tear energy for some of the pulps increases as the fiber strength increases; but the increase is not as uniform, nor as consistent, as in the case of the tensile properties or the burst test. This interesting inversion between the ordinary Elmendorf tear test and the Institute in-plane tear test is indicative of the basic difference between the mode of tearing for each test.

THE EFFECT OF BONDING

The effect of an increase in bonded area of the handsheets on the mechanical properties is shown in Fig. 46-49. It should be kept in mind that what is plotted in the graphs is the unbonded area of the handsheet as measured by nitrogen gas adsorption. As the bonding in a particular handsheet increases,this number will decrease; that is, a higher unbonded area as plotted means a lower bonded area in the sheet and less bonding. Although there seems to be a fair degree of scatter in the data, some

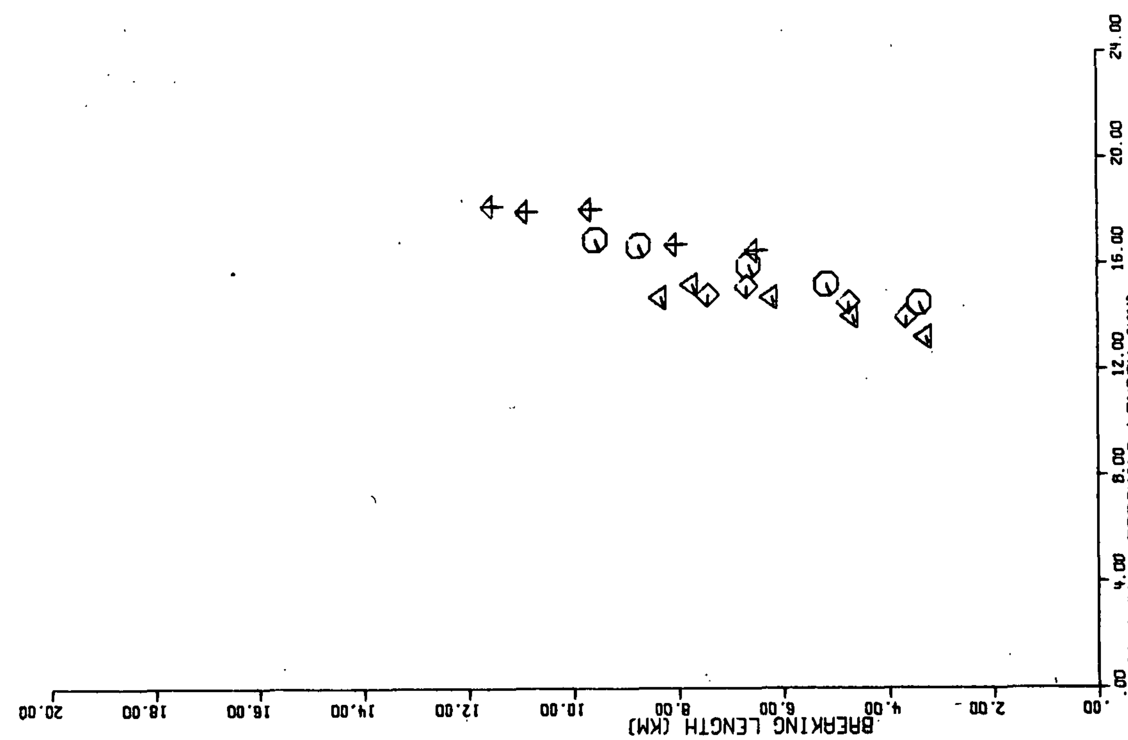


Figure 42. Effect of Fiber Strength on the Breaking Length

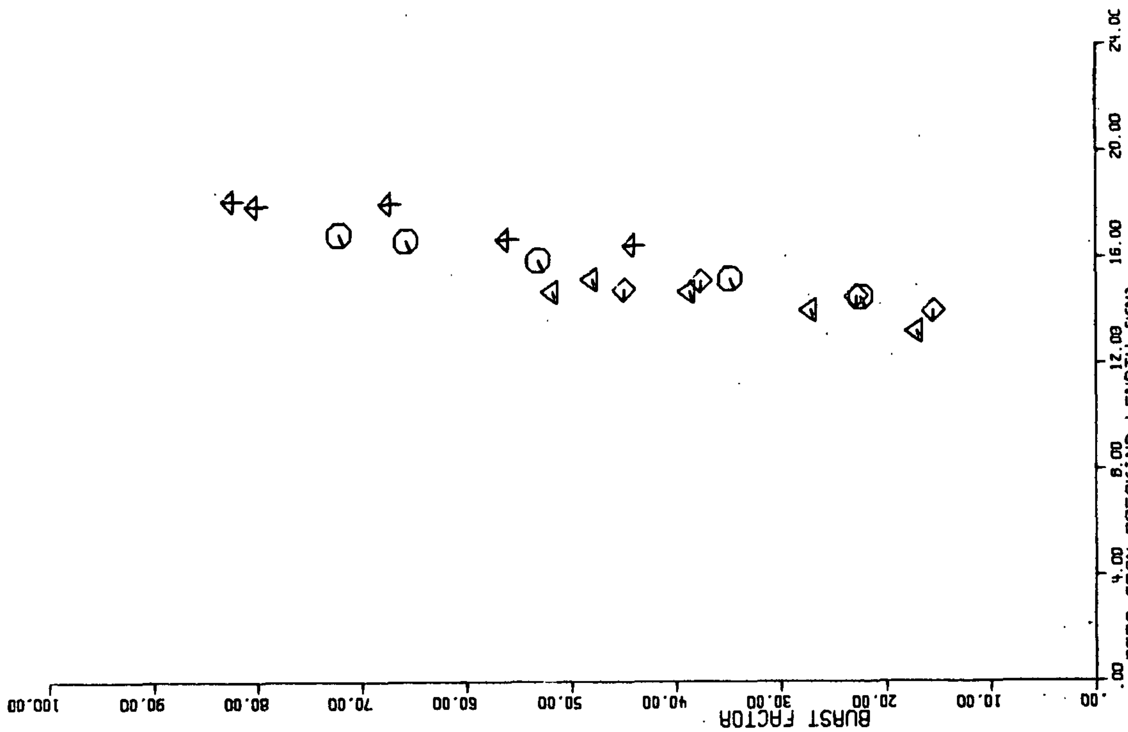


Figure 43. Effect of Fiber Strength on the Burst Factor

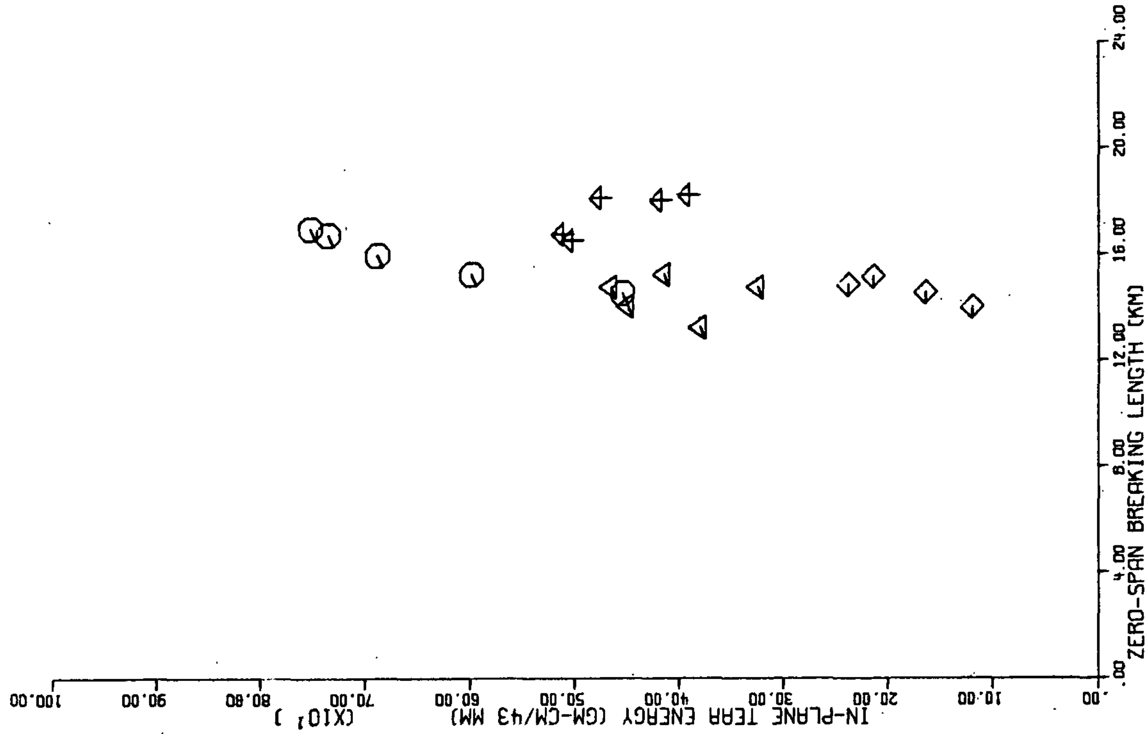


Figure 45. Scatter Diagram of Fiber Strength and In-Plane Tear Energy

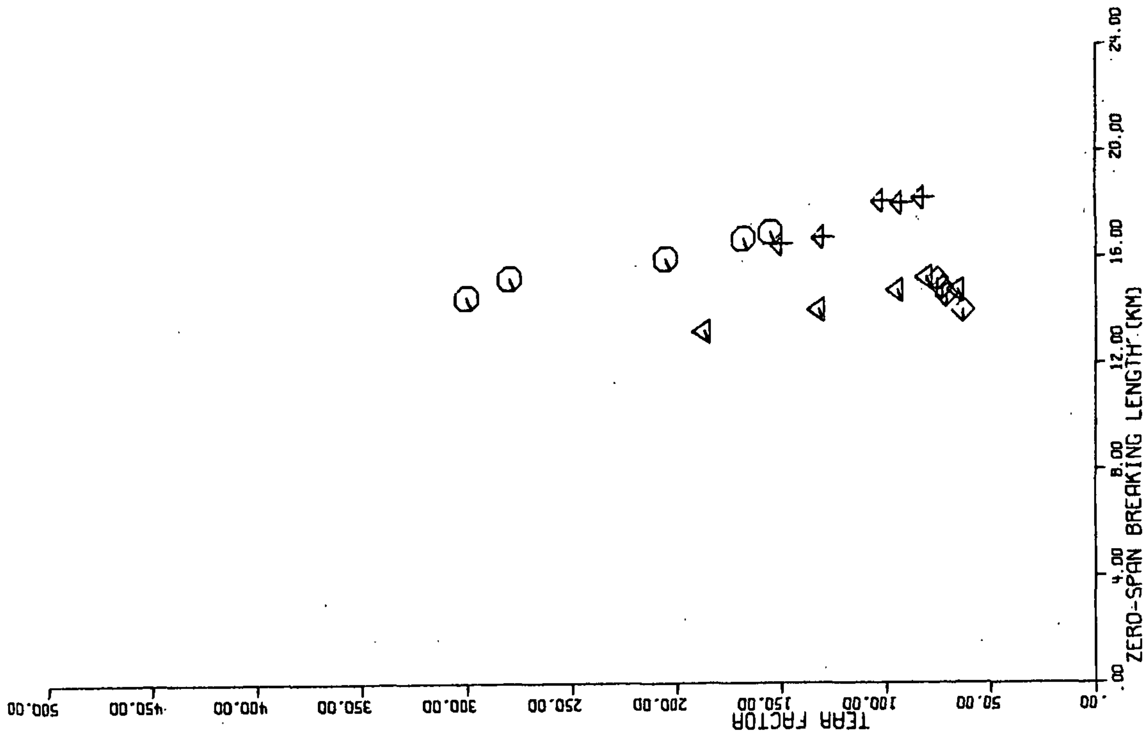


Figure 44. Scatter Diagram of Fiber Strength and Tear Factor

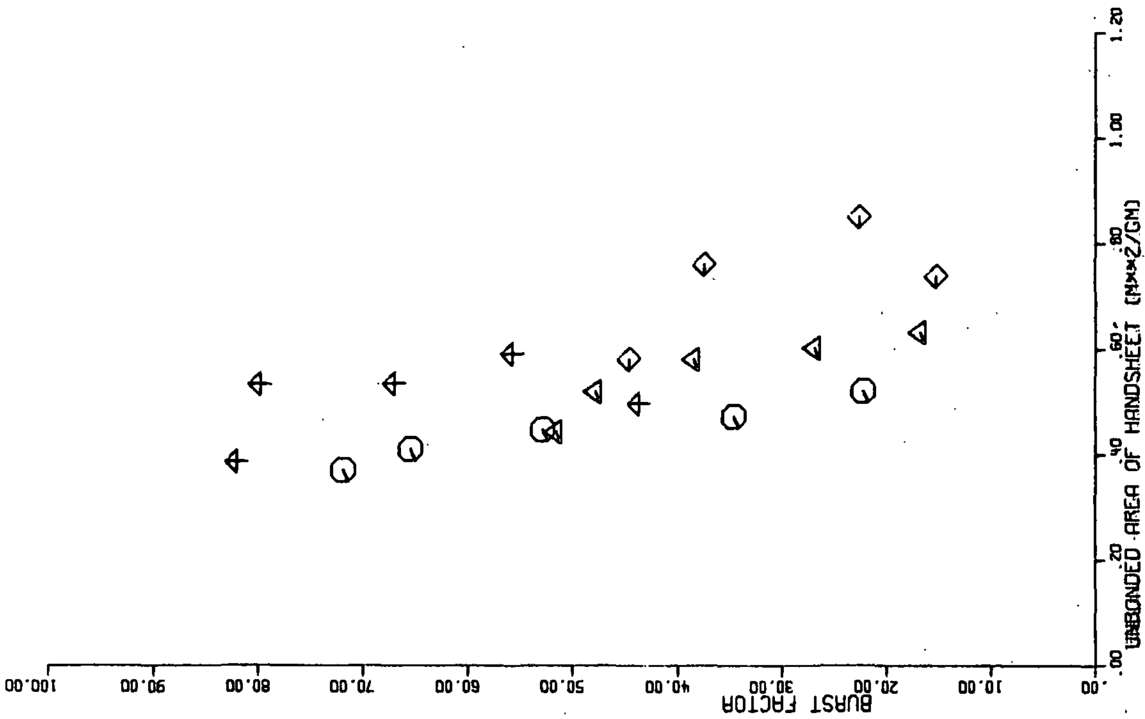


Figure 47. Effect of Bonding on Burst Factor

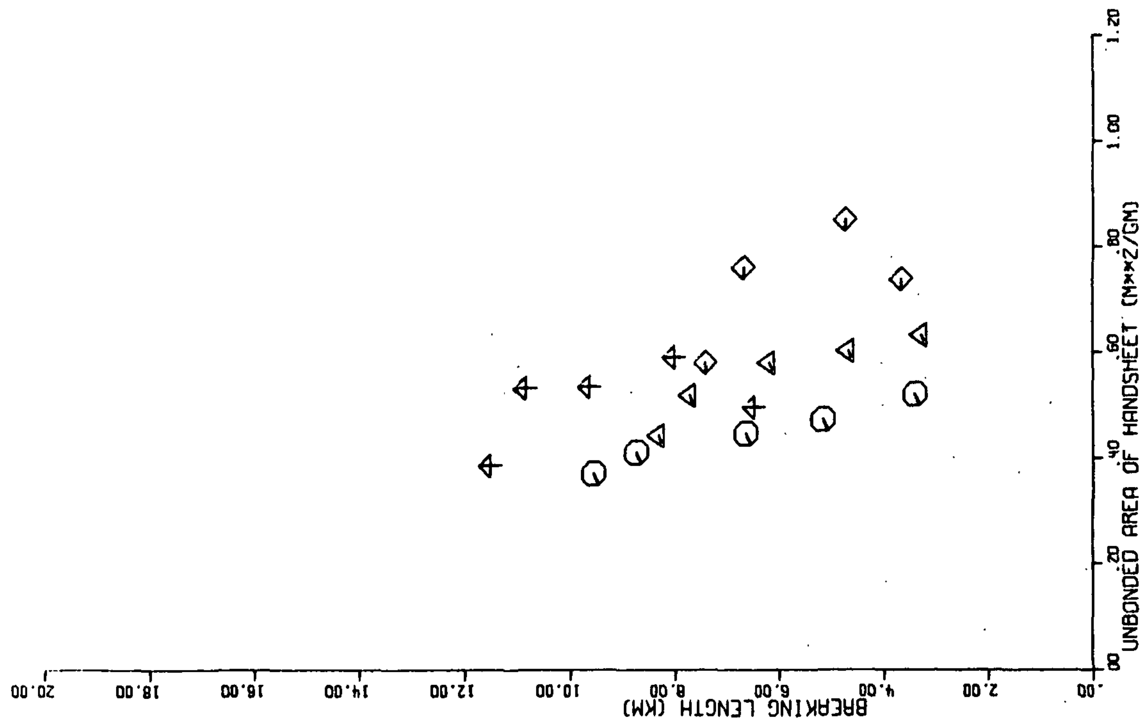


Figure 46. Effect of Bonding on Breaking Length

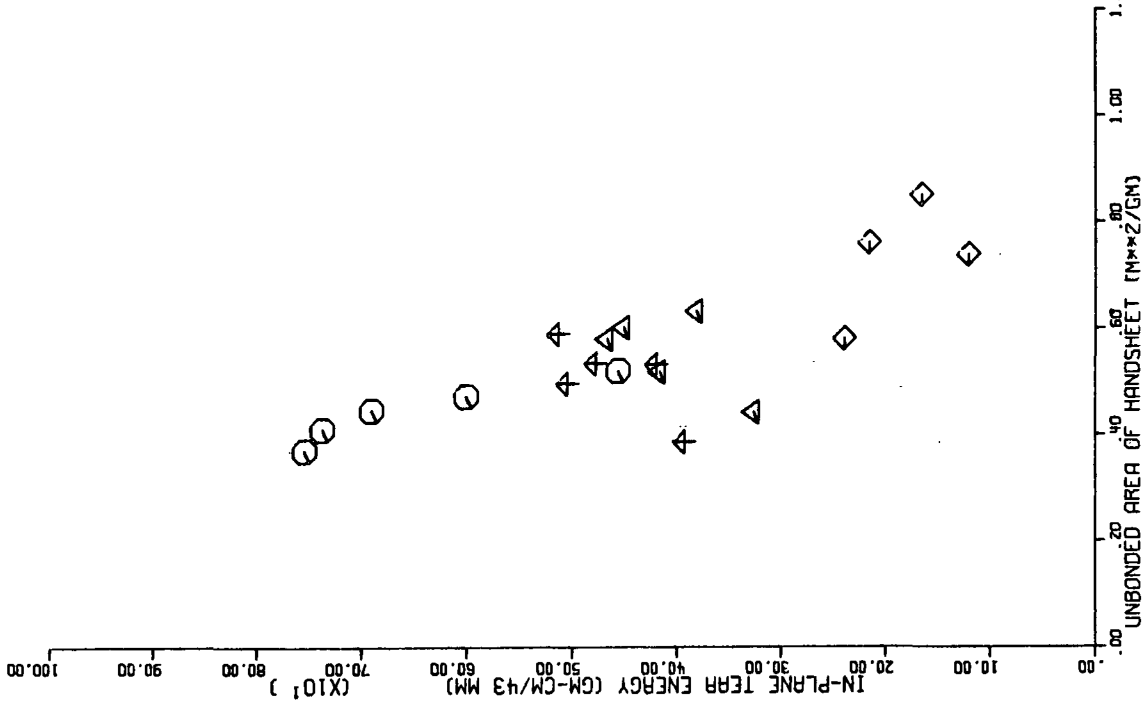


Figure 49. Effect of Bonding on In-Plane Tear Energy

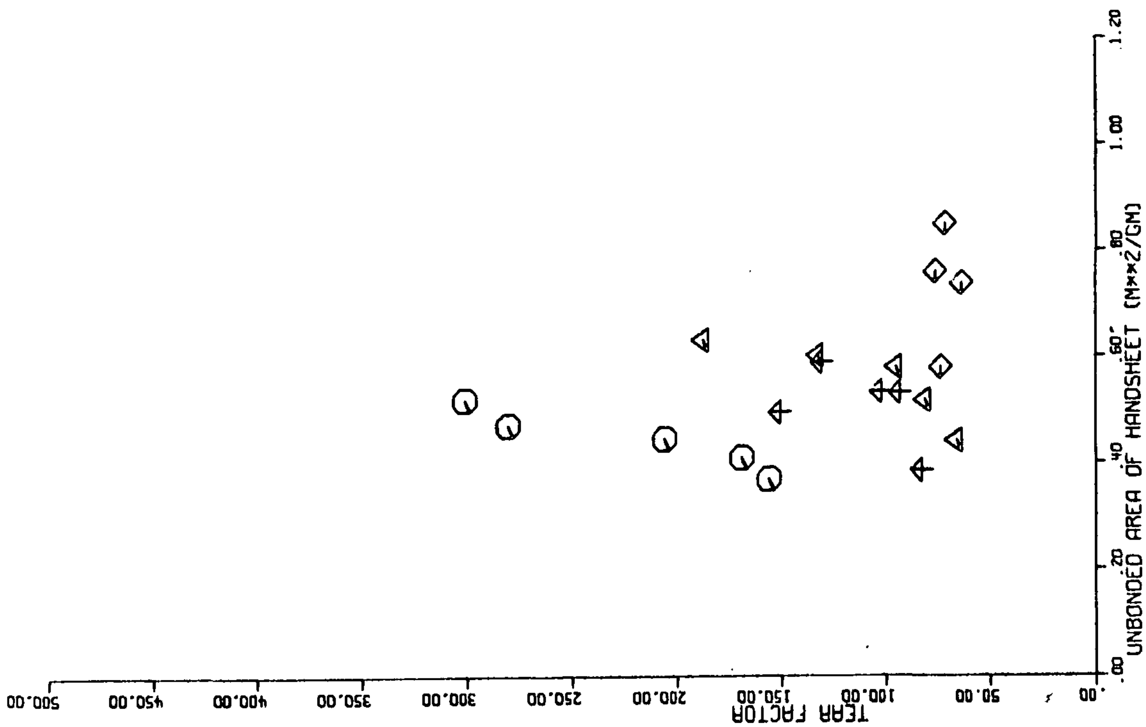


Figure 48. Scatter Diagram of Tear Factor and Unbonded Area of Handsheets

general trends are evident. For example, for a particular pulp, the breaking length increases as the degree of bonding increases. Although there is more scatter in the burst data, the same trend is evident. The test which scatters most, and for which no conclusion can be drawn, is that of Elmendorf tear factor.

The last of the four graphs shows a very unexpected trend in that the tear energy measured by the in-plane method shows a distinct increase with bonded area, or, in terms of the graph, a decrease with an increase in unbonded area. According to previous interpretations of the tearing process one would expect that as the sheet becomes more lightly bonded the fibers would pull out rather than breaking. The pulling-out of a fiber requires considerably more energy than breaking it, so one would have expected the more lightly bonded sheet to absorb more energy and produce a higher value of in-plane tear energy. Such a behavior was not observed, and the more highly-bonded pulps yielded higher in-plane tear energies. This was especially evident for the unbleached southern-pine kraft pulp (B).

The following reasonable explanation for this behavior was suggested by Dr. Van den Akker. When a fiber is strong, an increase in bonding should initially <u>increase</u> the tear energy due to the increased bonding and frictional effect involved in pulling the fibers from their original positions. If the bonding is further increased, however, a point should be reached where the fiber is no longer strong enough to resist breaking and the tear energy should fall. The frictional effect, combined with a high fiber strength, may explain the behavior of Pulp B.

DRAINAGE CHARACTERISTICS

The last of the four areas in which an attempt was made to correlate the mechanical properties was that of the drainage characteristics. The next eight figures (50-57) show clearly why in statistical terms such cross-plots of one

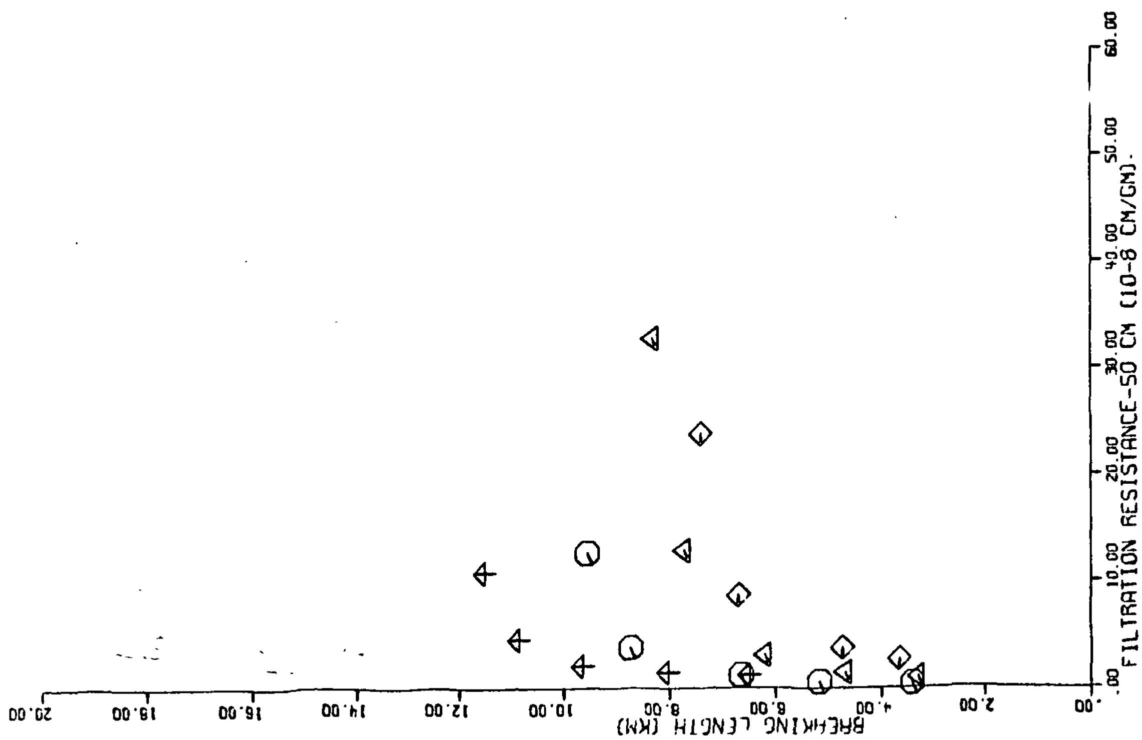


Figure 50. Parallel Changes in Breaking Length and Filtration Resistance with Beating

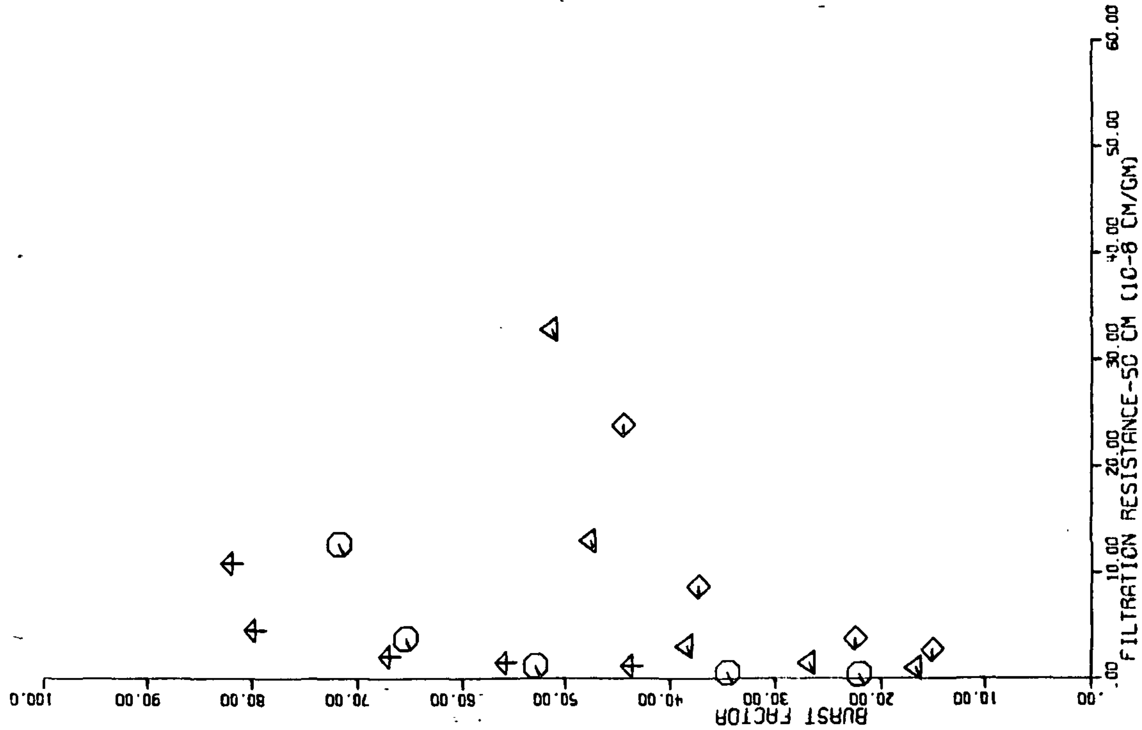


Figure 51. Parallel Changes in Burst Factor and Filtration Resistance with Beating

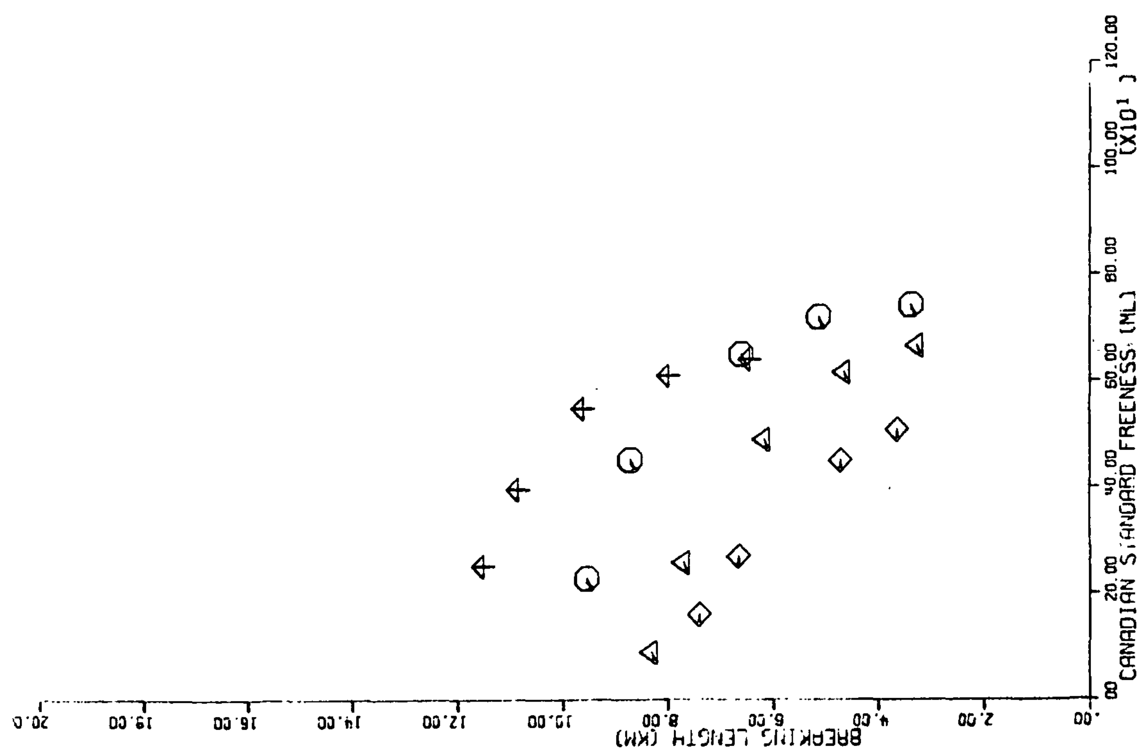


Figure 54. Scatter Diagram of Breaking Length and Canadian Standard Freeness

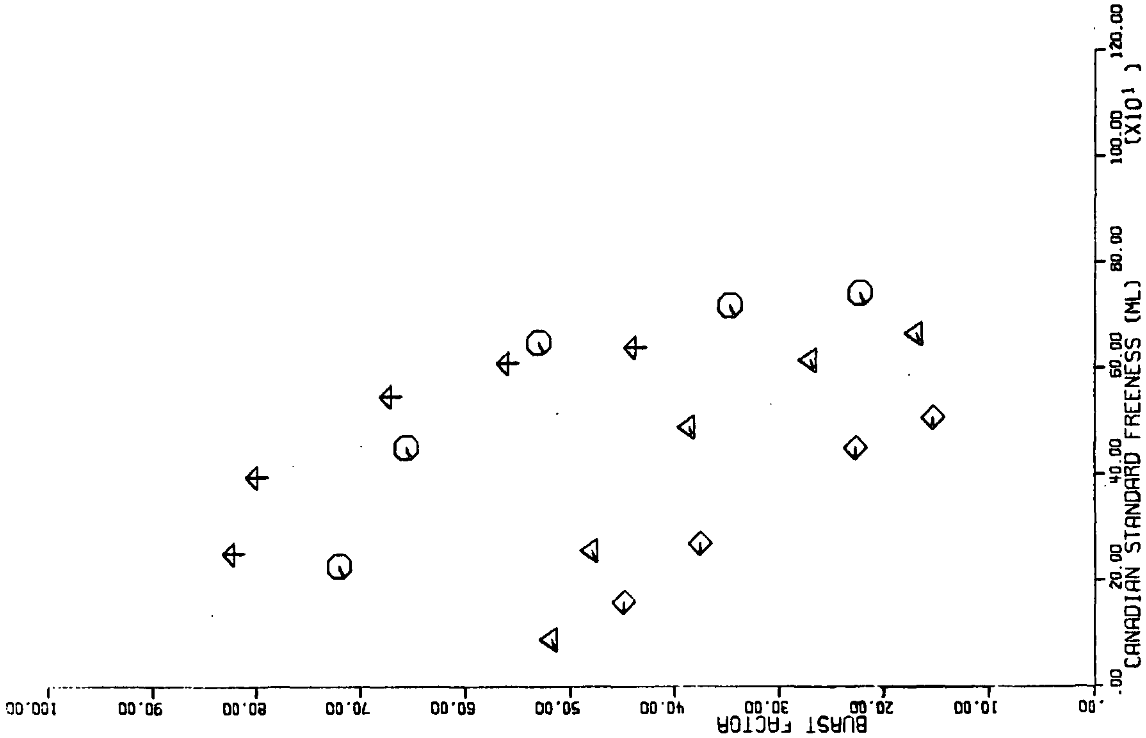


Figure 55. Scatter Diagram of Burst Factor and Canadian Standard Freeness

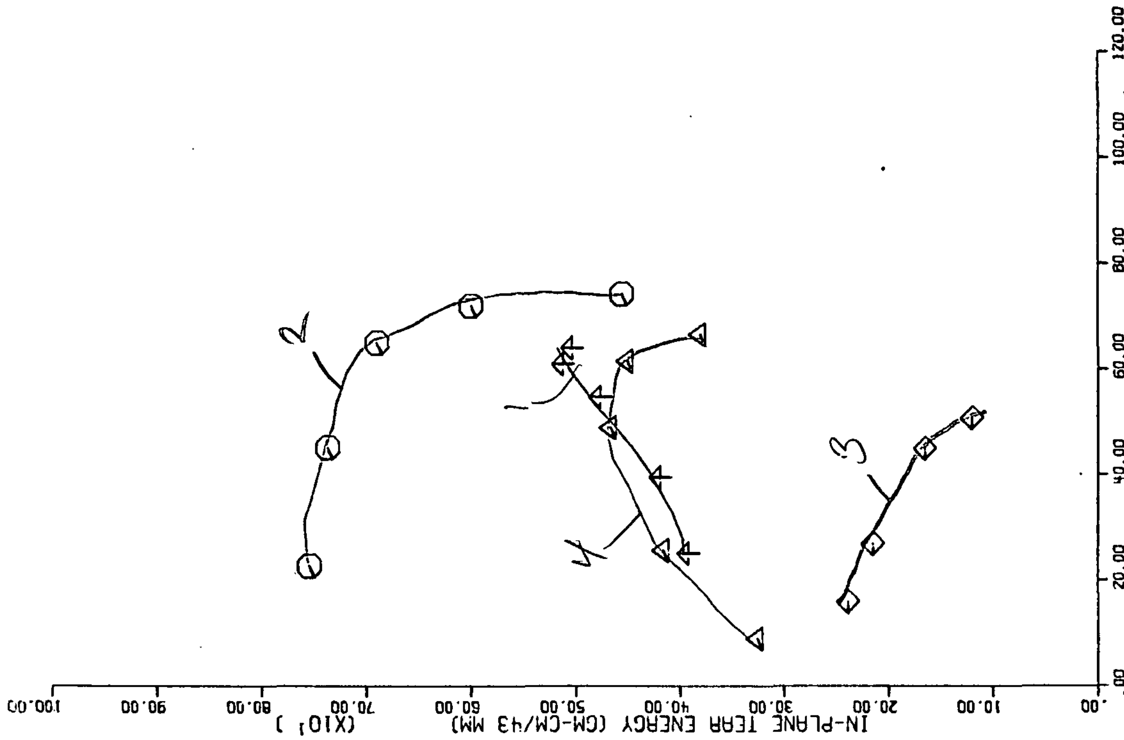


Figure 57. Scatter Diagram of In-Plane Tear Energy and Canadian Standard Freeness

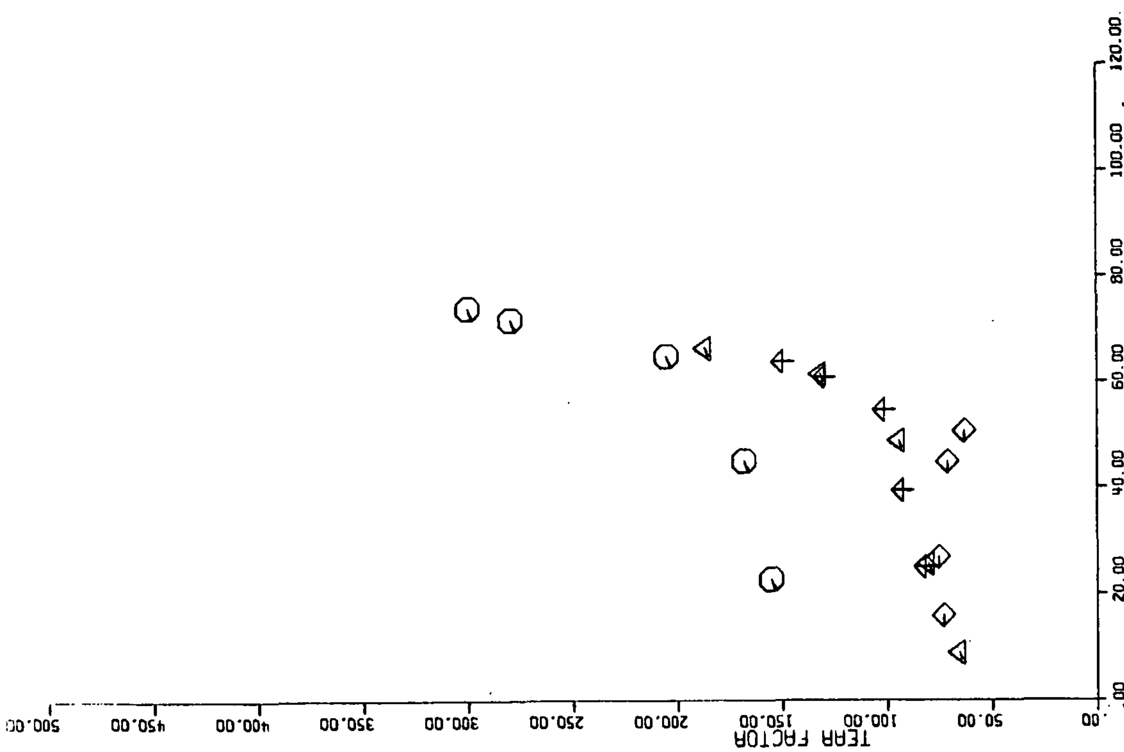


Figure 56. Scatter Diagram of Tear Factor and Canadian Standard Freeness

result *versus* another are called scatter diagrams. There seems to be no general relationship between the physical properties of the handsheets and the gross drainage properties as measured by either freeness or filtration resistance. There is some trend evident within a given test for a given pulp but this is, of course, a simple concomitant increase or decrease with the beating process and is not a causal effect. The overpowering influence of fines on the drainage resistance and on the freeness measurement was mentioned earlier in this report and is the reason why no better correlation between the drainage properties and the mechanical properties was observed.

One interesting conclusion, however, can be reached from these data if one looks at, for example, the plot of breaking length as a function of filtration resistance. It is evident that over an initial portion of the curve the tensile strength rises very quickly with only a small increase in the filtration resistance. The curve then breaks over and the filtration resistance begins to increase with a relatively small increase in tensile strength. This, of course, is a break-even point where the stock, which becomes slower and slower draining as the filtration resistance increases due to the increase in fines, shows very little accompanying increase in either burst or tensile. It is evident that some economical compromise situation, perhaps near the breakpoint or knee in the curve, could be selected for practical operations.

RELATIONSHIPS AMONG TESTS

The final section in the description and comparison of the physical test data concerns the comparison of one test *versus* another. This can be informative concerning the real meaning of the test which has been performed. Most of the relationships described herein have been previously noted in the literature or in previous reports.

Figure 58 shows the very good correlation between tensile energy absorption and the measured burst factor. The theoretical analysis of the burst test and the physical factors involved have been described previously by Dr. Van den Akker in the literature.

A number of graphs which were not reproduced in this report showed a random scatter when plotting tensile properties such as breaking length and tensile energy absorption *versus* in-plane or Elmendorf tear test. Likewise there was no evident correlation between the burst factor and any of the tear tests, nor would any be expected. Evidently, the localized rupturing mechanism which occurs in the tear test has little relationship to the tensile energy absorption which is the overall energy absorbed in stretching and eventually rupturing a sheet of paper under tension. This might be expected but is further amplified by the data shown in this report. The tensile energy absorbed for these samples is roughly one-half the product of the stretch or elongation at break and the breaking length so that an increase in either the stretch or the breaking length will produce a proportional increase in the tensile energy absorbed and an increase in the burst factor.

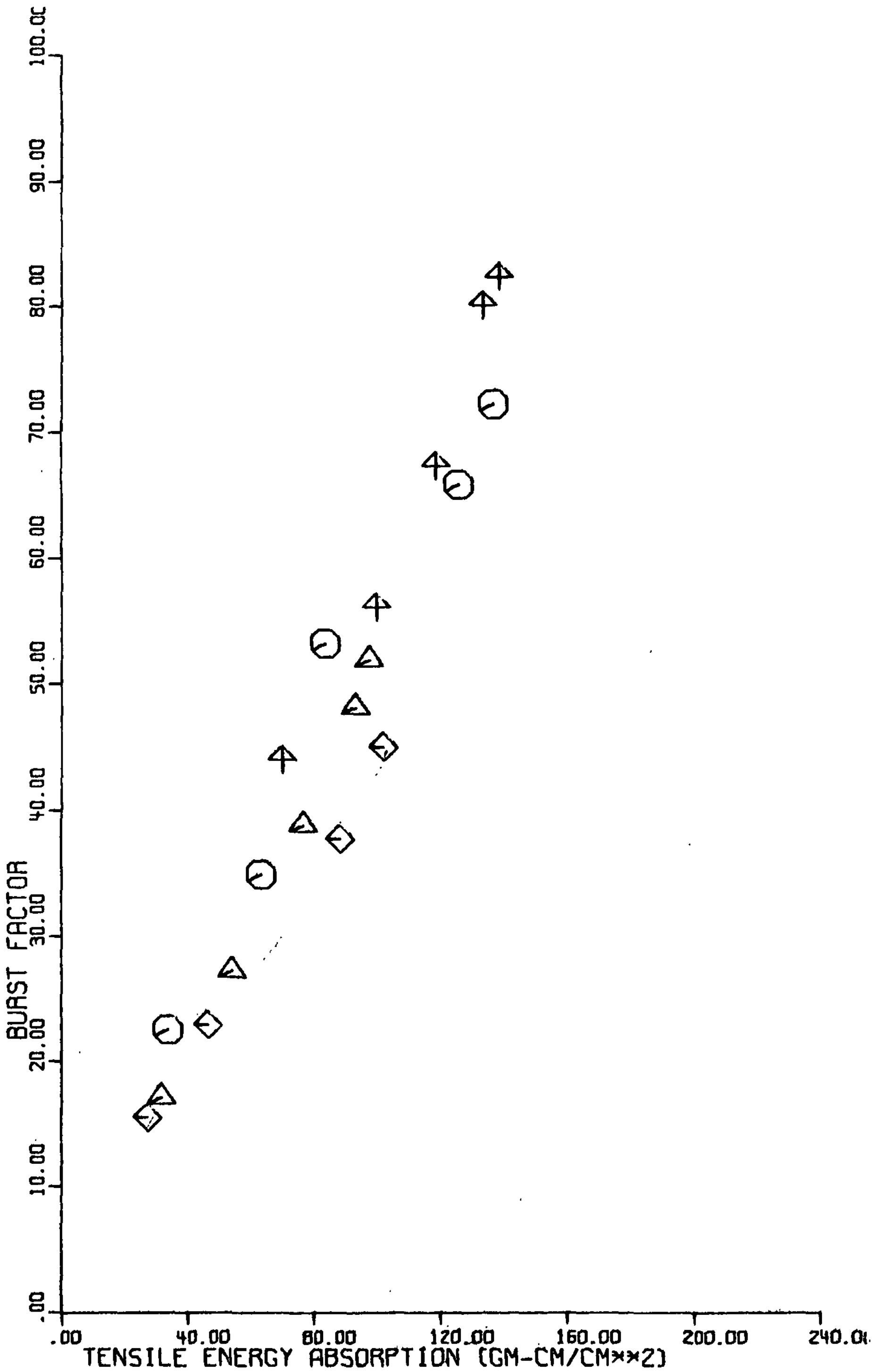


Figure 58. Correlation Between Burst Factor and Tensile Energy Absorption

FUTURE USE OF DATA

There are three main uses that could be made of the data included in this report.

1. One could use the statistical-correlational approach which would arrive at unbiased, quantitative estimates of multiple effects and thus be able to separate, or more clearly define, the actual effect of two or more of the variables at the same time. Such an approach would be more exact and perhaps yield more useful results than the simple qualitative observational approach which has been taken in this report. An example of this approach is that taken by Dr. Thode in Project 2211, Reports Three and Six.

2. One could apply semiempirical models of the beating process and the processes of fiber swelling and fragmentation. The effects on sheet properties could be developed along the lines given by M. W. Kane or J. d'A. Clark. Such approaches depend very heavily upon practical empirical tests of secondary quantities which are related in some way to the fundamental properties of bonding, fiber strength, and fiber length.

3. One could follow the direct theoretical approach based upon the fiber length distribution, individual fiber strengths, and the properties of individual bonds in tension and torsion. A sound foundation has been laid in this area by Dr. Van den Akker and further progress should be evident in the years to come.

There are difficulties, of course, in applying Method 1, the statistical approach, in the general field of pulp characterization. Very often the results which are obtained are specific to a given pulp and processing condition. Uncontrolled or unrecognized factors also may enter into the result, and it is very difficult and very dangerous to generalize or extrapolate such data.

Method 3, the direct theoretical approach, although potentially very powerful and fruitful in the long run, is as yet only in its infancy and the practical applications which are possible from the theoretical approach are as yet limited. The primary usefulness of the theory is in defining and illustrating the fundamental concepts of paper structure in idealized situations to help us understand better the processing behavior and end-use performance of paper.

The second approach seems presently the most practical for an industrial laboratory provided it is based on an understanding of the fundamental characteristics of pulp and how these characteristics are related to the empirical tests which are performed. The further step of correlating these empirical tests to the sheet properties of both machine-made paper and handsheets would, of course, be the function of each particular laboratory.

Although these three approaches are useful in their specific areas the primary use of the data in this report is to gain insight into the processing and paper properties of specific pulps and to interpret these properties in terms of generally applicable fundamental pulp characteristics.

ACKNOWLEDGMENTS

It is obvious that the data contained in this report represent the combined effort of many persons on the Institute staff. Robert Fumal, Albert van Beuningen, Donald Fird, and Robert Gertz are to be commended on their cooperation and diligence in performing various phases of the pulp preparation and handsheet testing. Lester Nett was especially helpful in the performance of the dynamic gas adsorption experiments and in other ways also. Larry Leporte carried the main responsibility for the work on the commercial drainage resistance analyzer, and Bruce Andrews supervised the research filtration resistance analysis work done by James Tierney. As always, Marguerite Davis did a fine job in determining the fiber length distribution for these many samples.

The possibility of drawing on so many and varied talents has been a real help, and is, of course, one of the primary advantages of a central research institute in a study which covers such diverse areas.

Thanks are also due to Dr. T. Alfred Howells for his assistance and guidance from the beginning to the final reporting of this phase of Project 2406.

THE INSTITUTE OF PAPER CHEMISTRY

Robert A. Holm

Robert A. Holm, Research Fellow
Special Processes Group
Technology Section

APPENDIX I

TABULATION OF DATA

TABLE VIA

TEST CODE IDENTIFICATION

1 Beating time (min.)

2 Canadian Standard freeness (ml.)

3 Schopper-Riegler freeness (ml.)

4 Bauer McNett analysis

5 Fiber length distribution

6 Number-average fiber length (mm.)

7 Weighted-average fiber length (mm.)

8 Grid-count fiber length (mm.)

9 Basis weight (g./m.^{2})

10 Thickness (microns)

11 Ovendry density (g./cm.^{3})

12 Breaking length (km.)

13 Stretch (%)

14 Burst factor

15 Tear factor

16 Tensile energy absorption (g.-cm./cm.^{2})

17 In-plane tear energy (g.-cm./43 mm.)

18 Zero-span breaking length (km.)

19 Sheet moisture (%)

20 z-tensile strength (kg./cm.^{2})

21 Scattering coefficient (cm.^{2}/g.)

22 Unbonded area of handsheet (m.^{2}/g.)

TABLE VIA (Continued)

TEST CODE IDENTIFICATION

23	Area of unbonded fibers ($m.^2/g.$)
24	Hydrodynamic volume ($cm.^3/g.$)
25	Hydrodynamic surface (10^{+3} $cm.^2/g.$)
26	Filtration resistance
27	Filtration resistance-50 cm. (10^{-8} cm./g.)
28	DRA filtration resistance at 50 cm. (10^{-8} cm./g.)

TABLE VIB

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 1	2	3	4[c]	5[c]
100	0.	0.	0.	0.	0.
105	5.	665.	860.	0.	0.
110	10.	615.	845.	0.	0.
120	20.	490.	787.	0.	0.
140	40.	257.	592.	0.	0.
160	60.	90.	360.	0.	0.
200	0.	0.	0.	0.	0.
205	5.	742.	885.	0.	0.
210	10.	720.	870.	0.	0.
220	20.	650.	850.	0.	0.
240	40.	452.	750.	0.	0.
260	60.	227.	517.	0.	0.
300	0.	0.	0.	0.	0.
305	5.	507.	802.	0.	0.
310	10.	450.	765.	0.	0.
320	20.	270.	640.	0.	0.
330	30.	160.	482.	0.	0.
400	0.	0.	0.	0.	0.
405	5.	640.	855.	0.	0.
410	10.	610.	840.	0.	0.
420	20.	547.	822.	0.	0.
440	40.	395.	750.	0.	0.
460	60.	252.	620.	0.	0.
0	0.	0.	0.	0.	0.
0	5.	100.	100.	0.	0.

[a] Pulps identified by pulp number and minutes of beating .

[b] For list of test codes, see p. 67-68.

[c] Zero (0.) entries represent no data.

TABLE VIB (Continued)

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 6	7	8[c]	9	10
100	1.51	2.35	0.	0.0	0.0
105	1.72	2.49	0.	61.4	105.5
110	1.52	2.28	0.	61.5	99.2
120	1.13	1.91	0.	60.8	91.4
140	1.02	1.63	0.	62.2	87.0
160	1.03	1.66	0.	59.7	79.3
200	1.95	2.62	0.	0.0	0.0
205	2.06	2.72	0.	60.2	125.5
210	2.14	2.76	0.	61.3	117.2
220	2.13	2.72	0.	61.1	107.2
240	1.97	2.68	0.	60.4	99.1
260	1.98	2.63	0.	61.1	97.1
300	.65	.78	0.	0.0	0.0
305	.71	.87	0.	59.5	104.0
310	.62	.76	0.	58.5	96.5
320	.60	.72	0.	59.4	87.0
330	.59	.70	0.	60.1	83.8
400	1.67	2.28	0.	0.0	0.0
405	1.89	2.49	0.	59.1	95.2
410	1.56	2.12	0.	59.8	93.3
420	1.53	2.03	0.	59.4	87.6
440	1.45	1.98	0.	60.1	85.0
460	1.41	1.99	0.	60.2	82.5
0	0.00	0.00	0.	0.0	0.0
0	.50	.50	0.	10.0	20.0

[a] Pulps identified by pulp number and minutes of beating.

[b] For list of test codes, see p. 67-68.

[c] Zero (0.) entries represent no data.

TABLE VIB (Continued)

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 11	12	13	14	15
100	0.000[c]	0.00	0.00	0.0	0.0
105	.606	3.28	1.87	17.0	187.0
110	.620	4.67	2.32	27.1	132.0
120	.665	6.19	2.55	38.6	94.5
140	.716	7.71	2.52	47.9	80.3
160	.752	8.31	2.55	51.7	65.4
200	0.000	0.00	0.00	0.0	0.0
205	.479	3.40	2.20	22.3	300.5
210	.523	5.15	2.75	34.8	280.0
220	.570	6.64	2.87	53.0	205.5
240	.610	8.74	3.47	65.7	168.5
260	.629	9.55	3.40	72.0	155.5
300	0.000	0.00	0.00	0.0	0.0
305	.572	3.66	1.67	15.3	63.0
310	.606	4.74	2.25	22.8	70.7
320	.683	6.68	3.05	37.6	75.5
330	.718	7.41	3.15	44.9	73.0
400	0.000	0.00	0.00	0.0	0.0
405	.620	6.47	2.60	43.9	150.0
410	.640	8.02	2.92	56.0	130.0
420	.678	9.64	3.10	67.2	101.5
440	.706	10.85	3.05	80.0	92.2
460	.730	11.52	2.97	82.3	82.1
0	0.000	0.00	0.00	0.0	0.0
0	.100	2.00	.50	10.0	50.0

a Pulps identified by pulp number and minutes of beating.

b For list of test codes, see p. 67-68.

c Zero (0.) entries represent no data.

TABLE VIB (Continued)

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 16	17	18	19	20
100	0.0[c]	0.0	0.00	0.00	0.00
105	31.5	379.5	13.25	7.60	4.58
110	54.0	450.0	14.05	7.60	7.10
120	76.7	466.0	14.75	7.65	9.97
140	93.2	414.5	15.25	7.70	12.20
160	97.6	324.5	14.75	7.85	12.30
200	0.0	0.0	0.00	0.00	0.00
205	33.6	455.0	14.50	8.50	3.78
210	63.3	598.5	15.25	8.60	5.01
220	83.7	688.5	15.95	8.55	7.60
240	126.0	735.5	16.70	8.60	10.06
260	136.7	753.0	16.95	8.65	10.35
300	0.0	0.0	0.00	0.00	0.00
305	27.0	119.0	14.00	7.55	5.34
310	46.3	163.5	14.55	7.55	8.03
320	88.2	214.0	15.15	7.65	14.00
330	101.9	238.0	14.85	7.70	17.30
400	0.0	0.0	0.00	0.00	0.00
405	69.8	503.0	16.50	7.80	5.57
410	100.0	512.0	16.75	7.75	7.40
420	118.8	476.0	18.10	7.85	10.65
440	133.4	418.0	18.05	7.85	12.80
460	138.9	391.0	18.25	7.95	13.35
0	0.0	0.0	0.00	0.00	0.00
0	20.0	100.0	2.00	1.00	2.00

[a] Pulps identified by pulp number and minutes of beating.

[b] For list of test codes, see p. 67-68.

[c] Zero (0.) entries represent no data.

TABLE VIB (Continued)

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 21	22	23	24	25
100	0.0[c]	0.000	0.000	0.000	0.000
105	295.0	.632	.781	2.750	10.300
110	268.0	.601	.836	2.570	12.600
120	240.0	.580	.809	2.700	17.800
140	208.0	.518	.935	2.870	33.400
160	176.0	.441	.889	2.910	52.400
200	0.0	0.000	0.000	0.000	0.000
205	212.5	.519	.728	2.680	7.300
210	194.5	.471	.791	2.860	9.200
220	173.5	.445	.763	2.960	11.700
240	153.5	.410	.779	3.040	19.900
260	143.5	.370	.810	3.450	34.100
300	0.0	0.000	0.000	0.000	0.000
305	434.5	.737	.907	2.460	16.400
310	403.5	.850	.816	2.560	20.400
320	345.5	.760	.827	2.800	30.600
330	304.5	.580	.792	3.230	43.600
400	0.0	0.000	0.000	0.000	0.000
405	277.5	.496	.886	2.800	11.800
410	261.0	.590	.918	2.770	13.400
420	228.0	.534	.889	2.890	16.000
440	208.0	.532	.995	3.100	22.300
460	188.0	.385	1.093	3.070	30.500
0	0.0	0.000	0.000	0.000	0.000
0	50.0	.100	.200	.500	10.000

[a] Pulps identified by pulp number and minutes of beating.

[b] For list of test codes, see p. 67-68.

[c] Zero (0.) entries represent no data.

TABLE VIB (Continued)

EXPERIMENTAL DATA

Pulp[a]	Test Code[b] 26	27	28	29	30
100	0.	0.000	0.000	0.[c]	0.[c]
105	0.	1.000	1.409	0.	0.
110	0.	1.520	1.964	0.	0.
120	0.	3.100	3.532	0.	0.
140	0.	12.960	8.120	0.	0.
160	0.	32.880	17.101	0.	0.
200	0.	0.000	0.000	0.	0.
205	0.	.400	.549	0.	0.
210	0.	.600	.796	0.	0.
220	0.	1.180	1.491	0.	0.
240	0.	3.740	3.377	0.	0.
260	0.	12.640	7.362	0.	0.
300	0.	0.000	0.000	0.	0.
305	0.	2.650	2.859	0.	0.
310	0.	3.780	3.855	0.	0.
320	0.	8.680	7.988	0.	0.
330	0.	23.930	15.594	0.	0.
400	0.	0.000	0.000	0.	0.
405	0.	1.180	1.775	0.	0.
410	0.	1.510	2.048	0.	0.
420	0.	2.120	2.768	0.	0.
440	0.	4.620	5.196	0.	0.
460	0.	10.880	8.951	0.	0.
0	0.	0.000	0.000	0.	0.
0	0.	5.000	2.000	0.	0.

[a] Pulps identified by pulp number and minutes of beating.

[b] For list of test codes, see p. 67-68.

[c] Zero (0.) entries represent no data.

APPENDIX II

FIBER LENGTH DISTRIBUTIONS

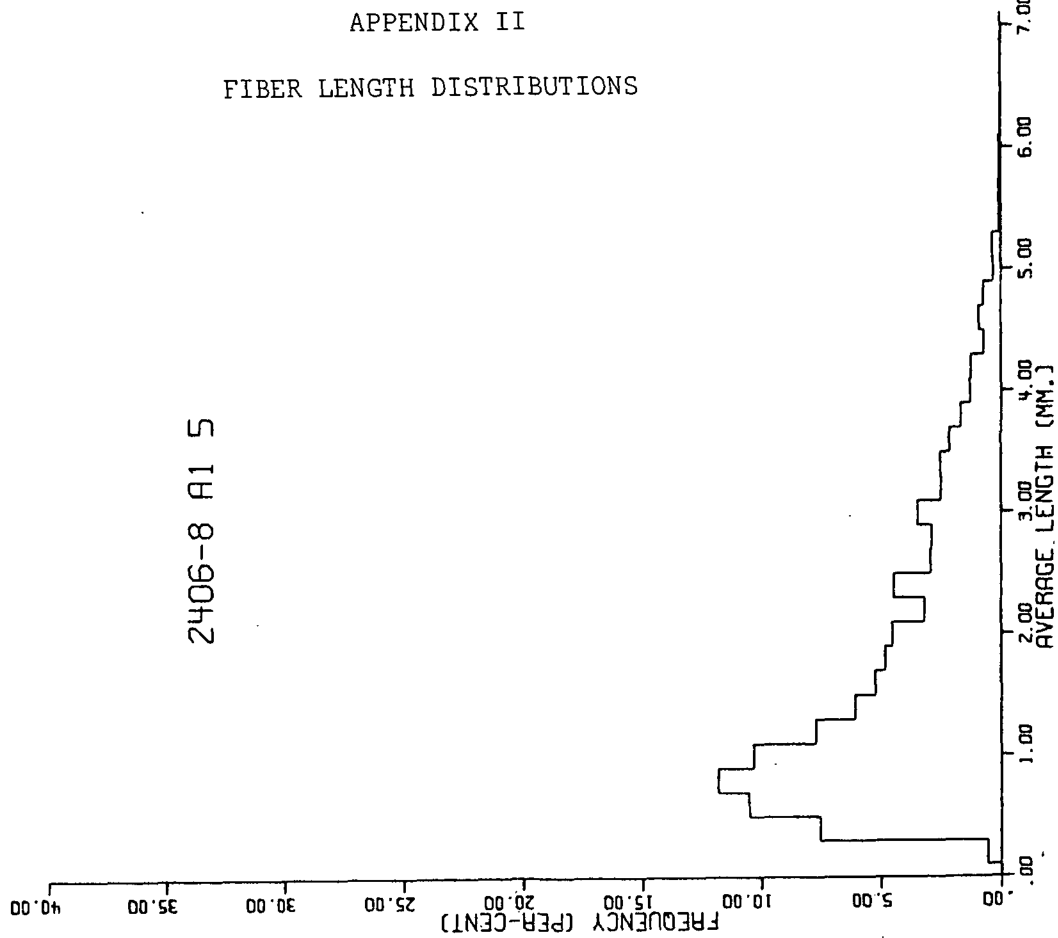


Figure 60. Pulp A Beaten for 5 Minutes

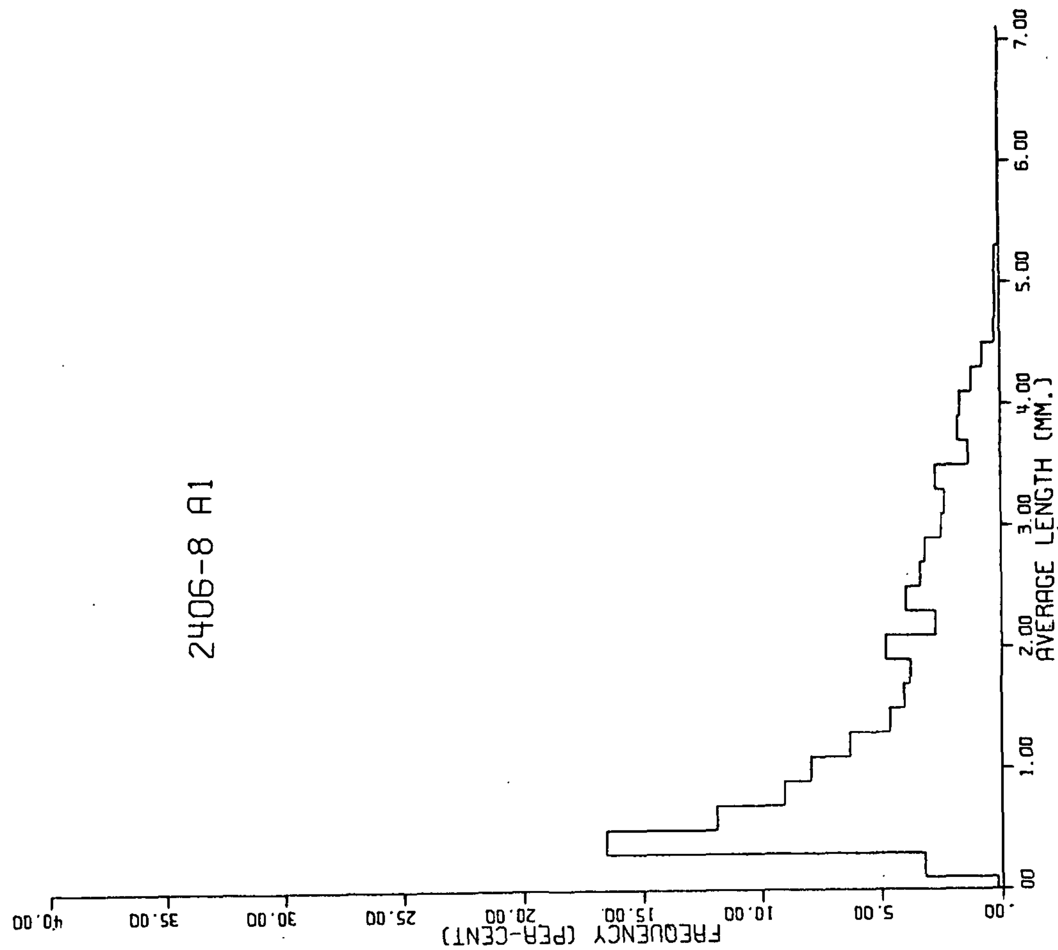


Figure 59. Fiber Length Distribution for Bleached Western Softwood Sulfite (Stockpile Pulp A - Unbeaten)

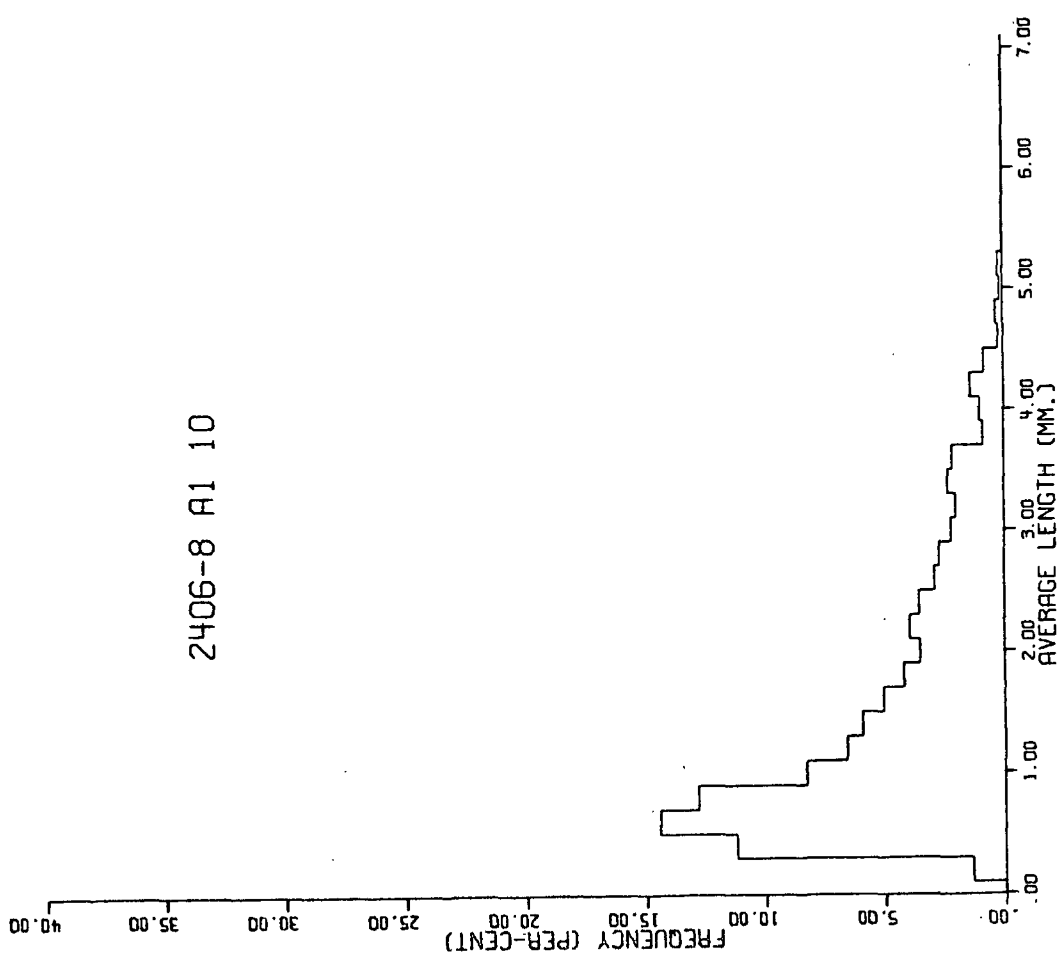


Figure 61. Pulp A Beaten for 10 Minutes

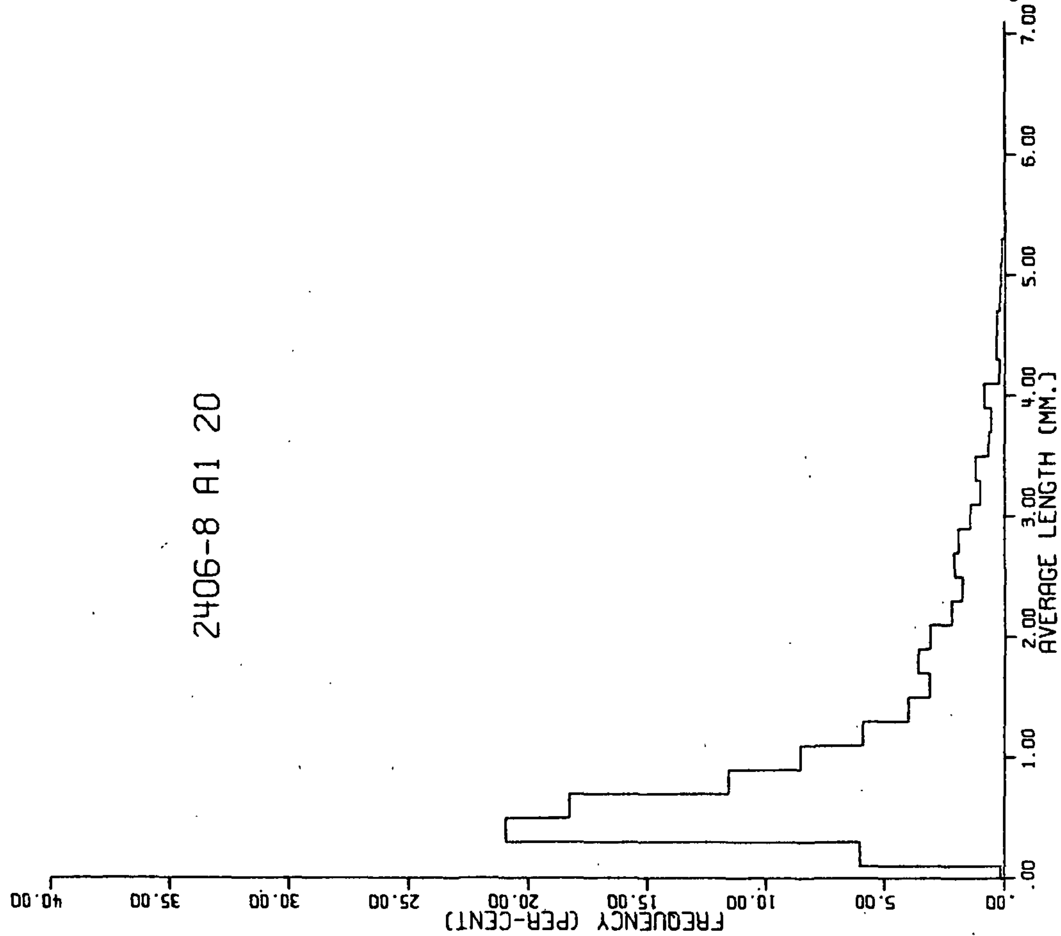


Figure 62. Pulp A Beaten for 20 Minutes

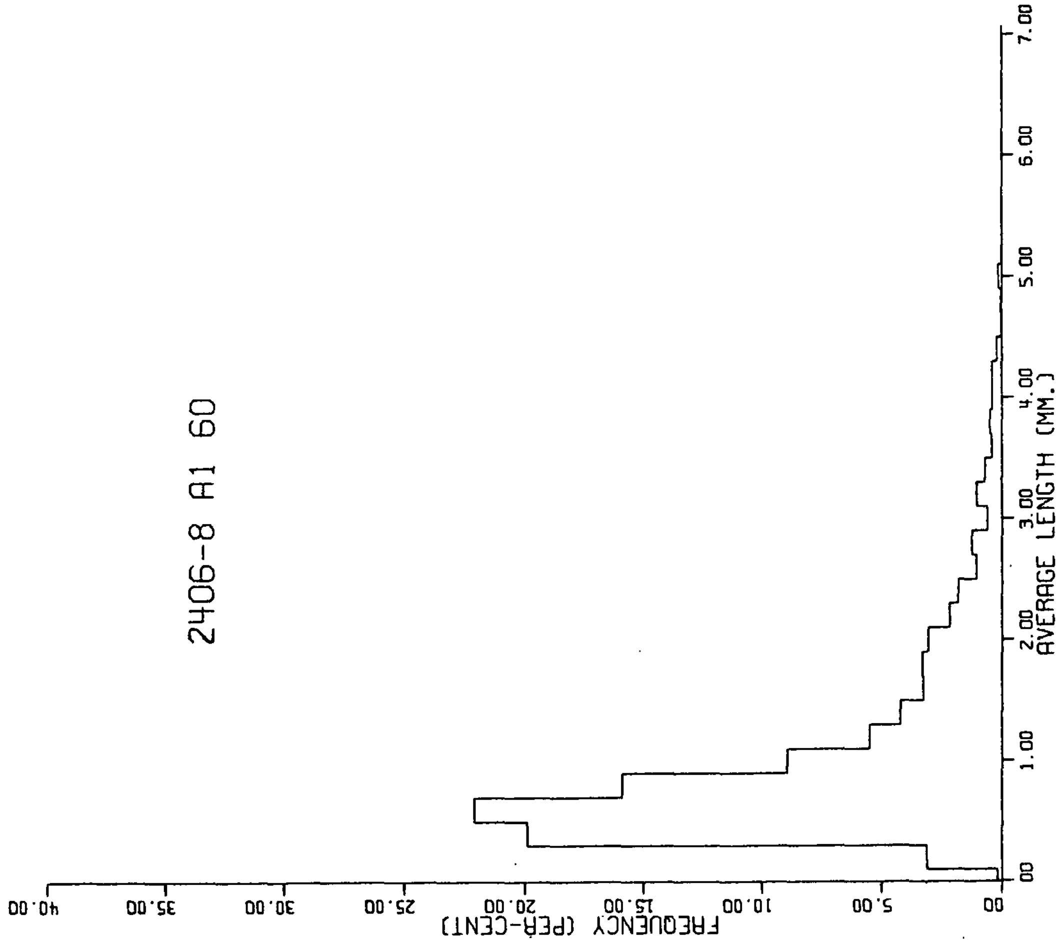


Figure 64. Pulp A Beaten for 60 Minutes

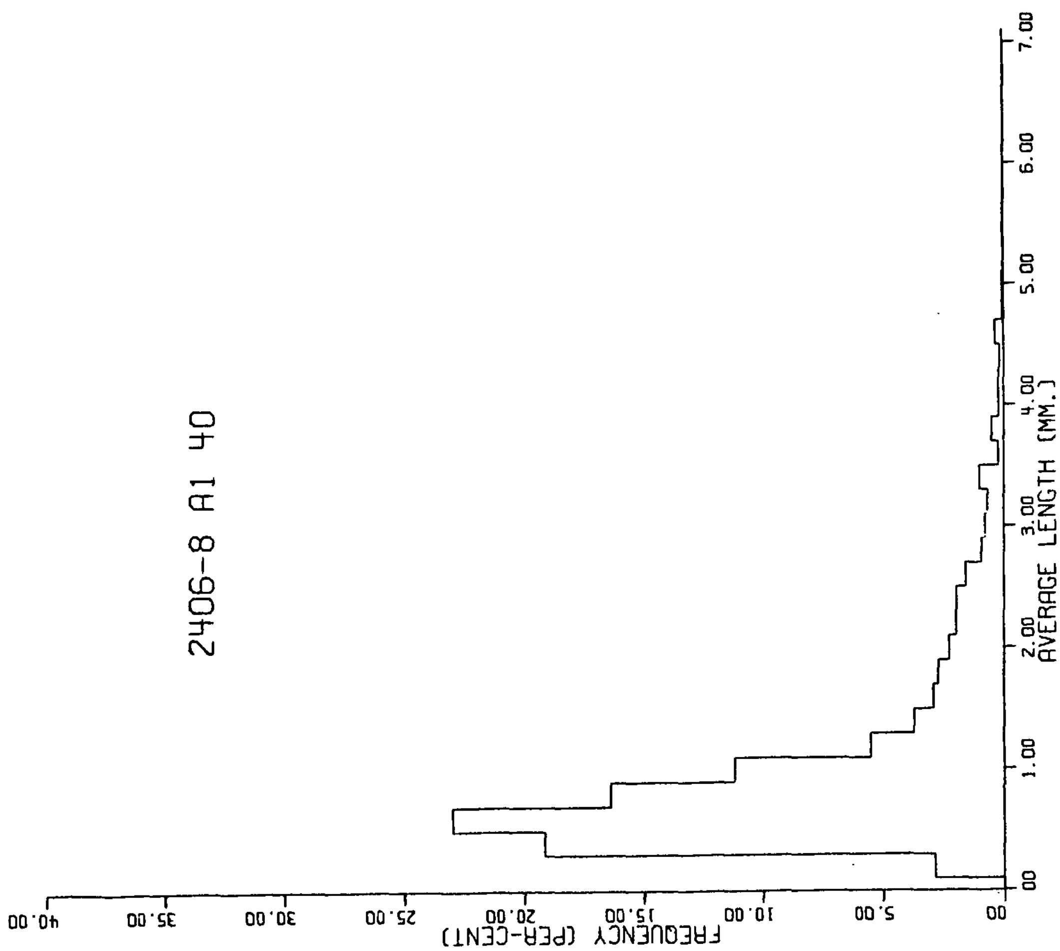


Figure 63. Pulp A Beaten for 40 Minutes

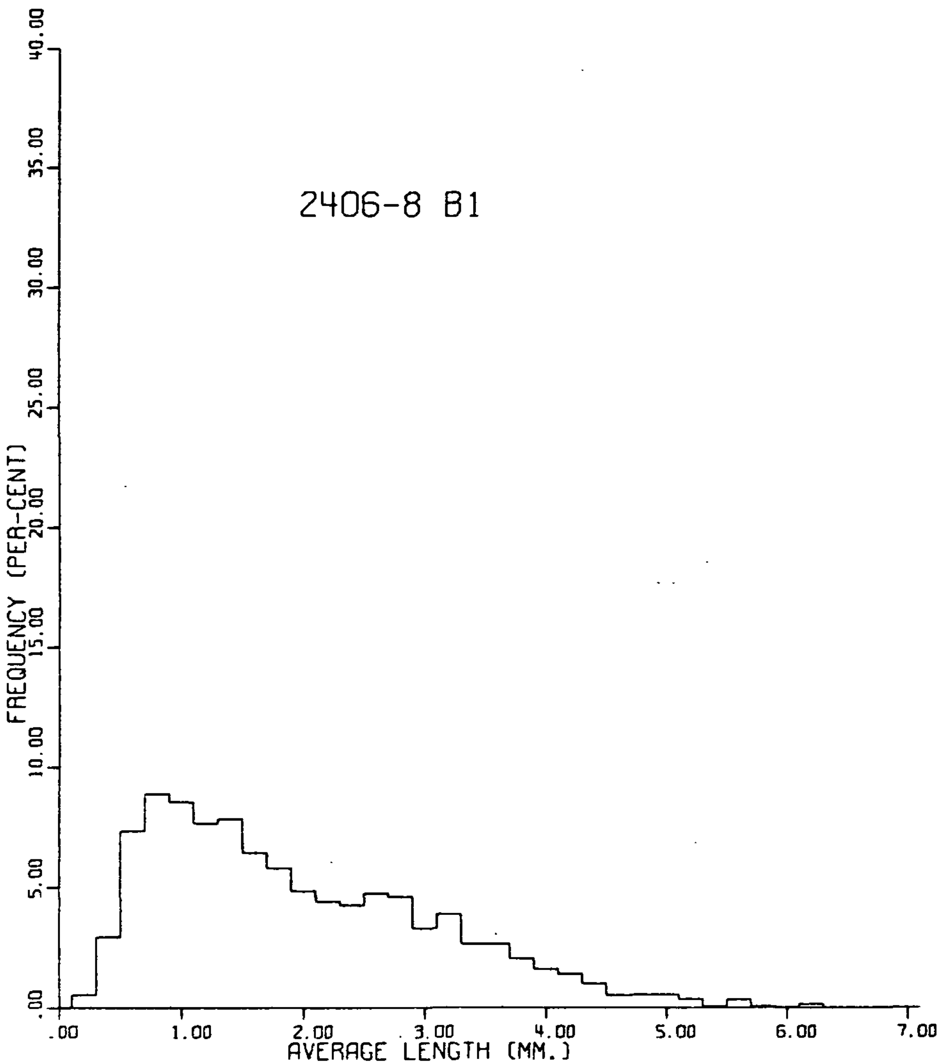


Figure 65. Fiber Length Distribution for Unbleached Southern Softwood Sulfate (Stockpile Pulp B - Unbeaten)

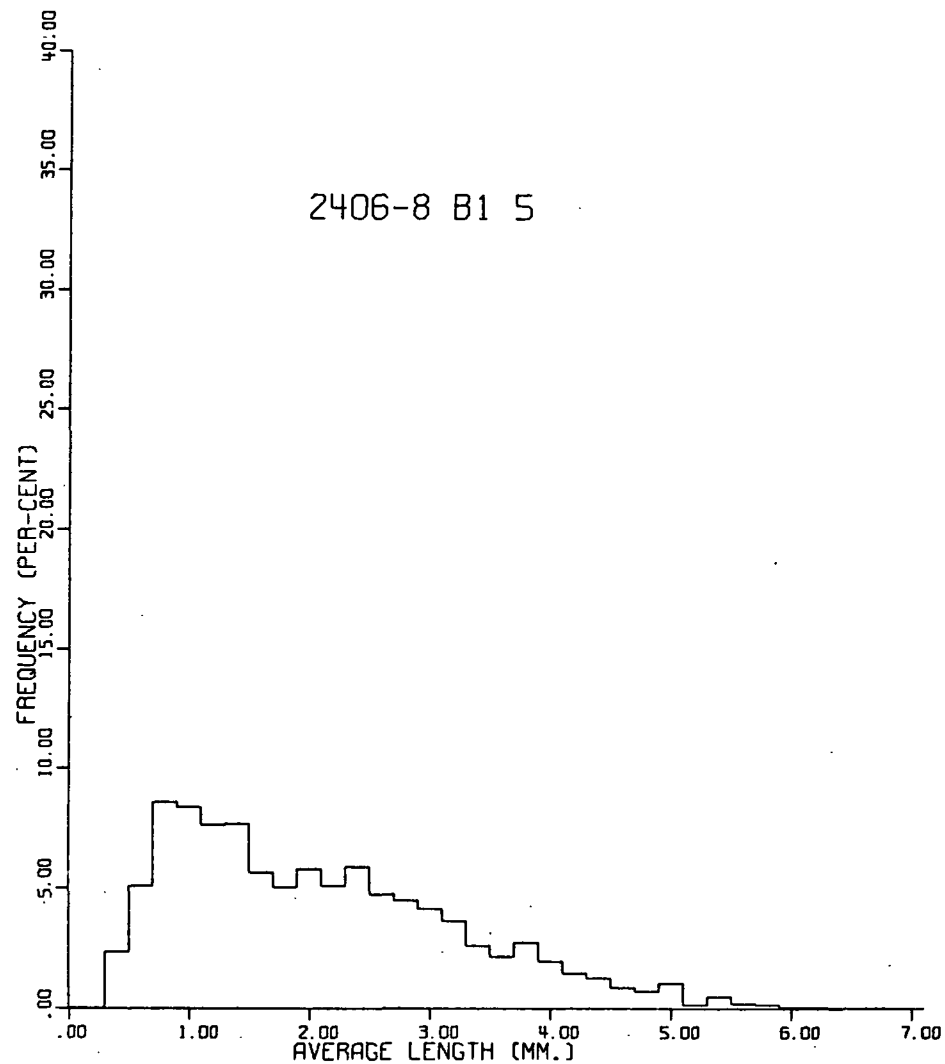


Figure 66. Pulp B Beaten for 5 Minutes

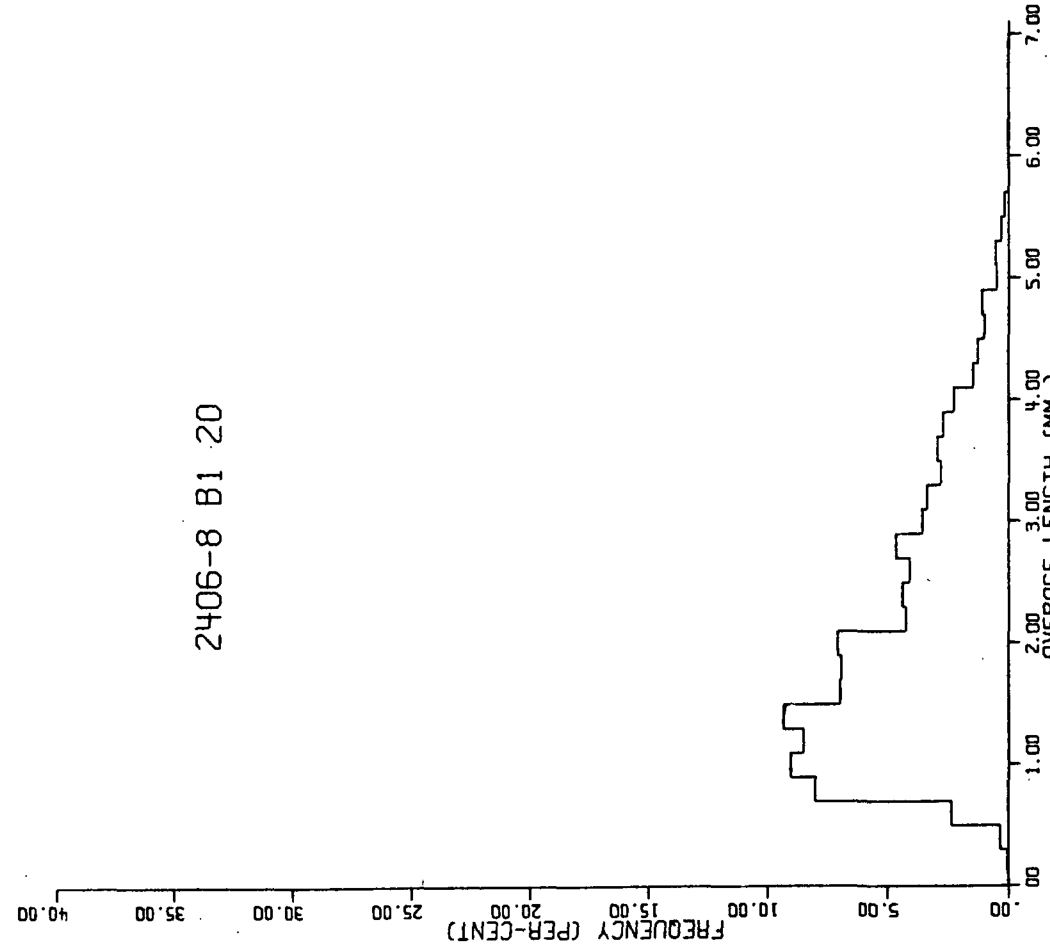


Figure 68. Pulp B Beaten for 20 Minutes

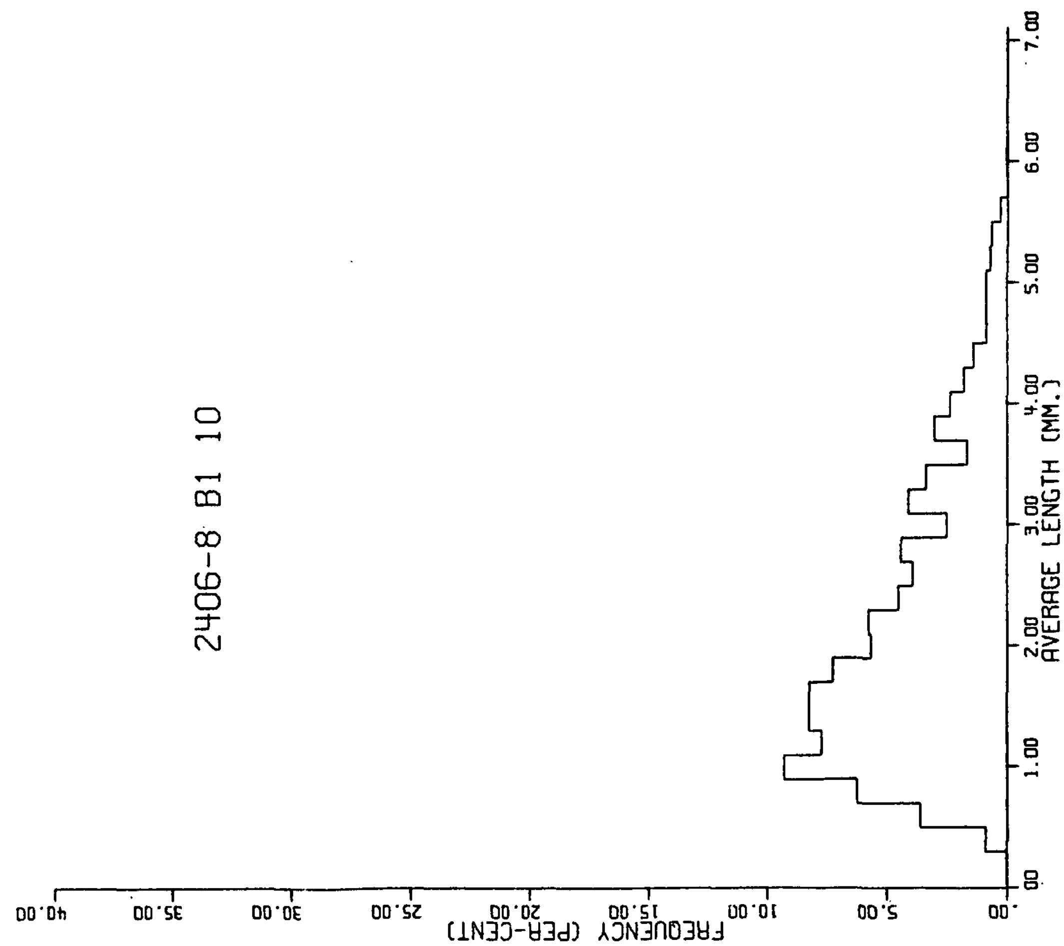


Figure 67. Pulp B Beaten for 10 Minutes

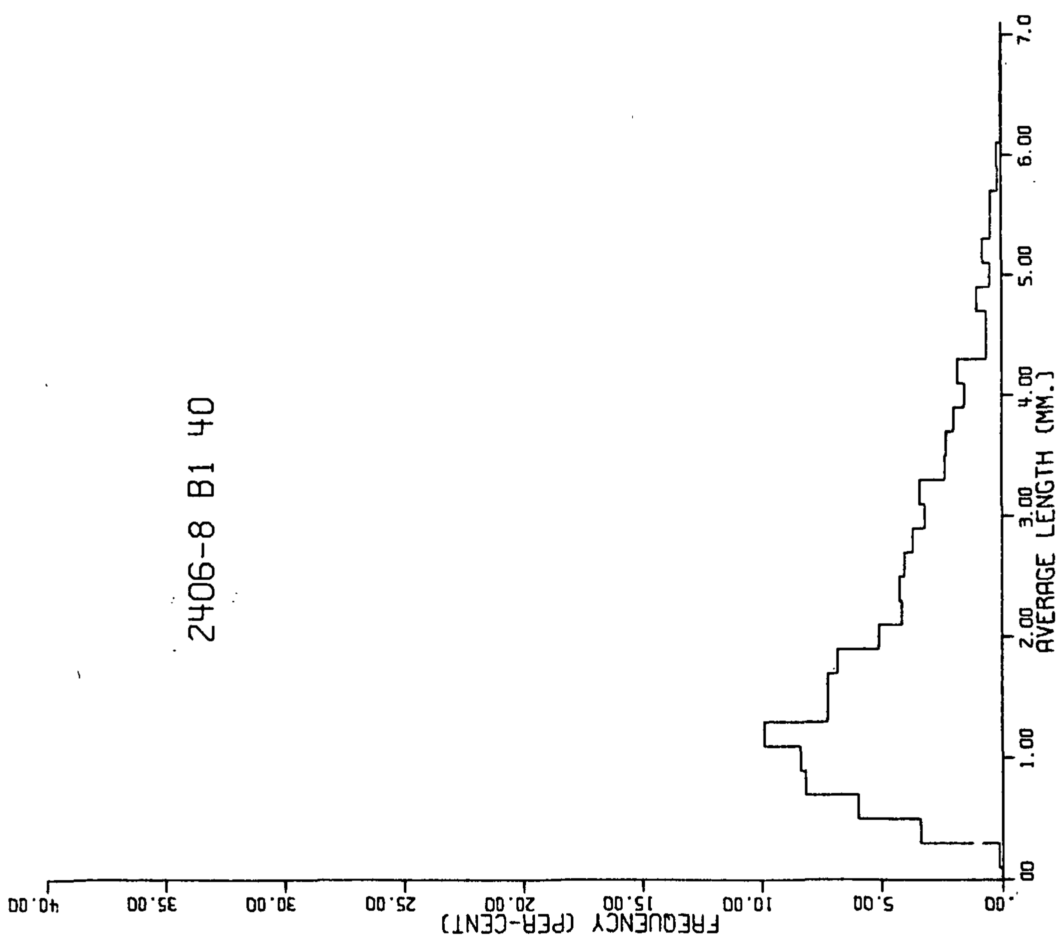


Figure 69. Pulp B Beaten for 40 Minutes

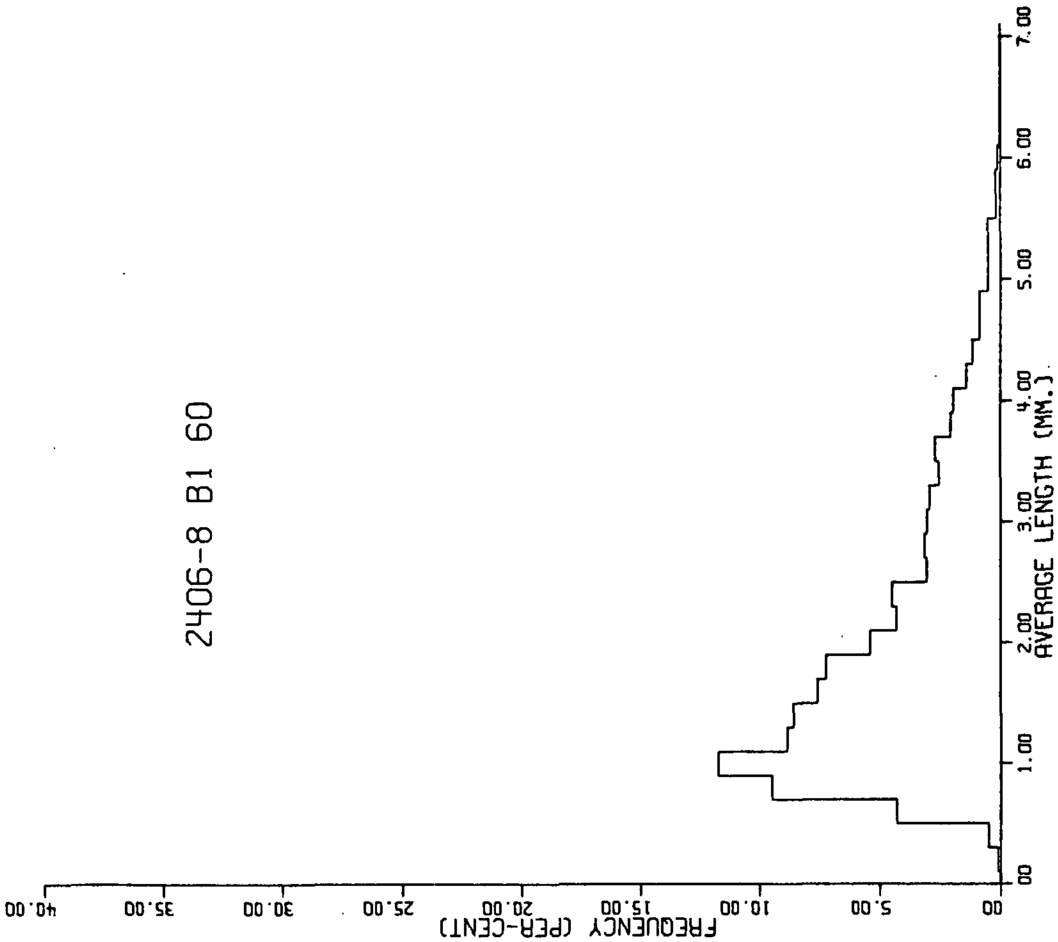


Figure 70. Pulp B Beaten for 60 Minutes

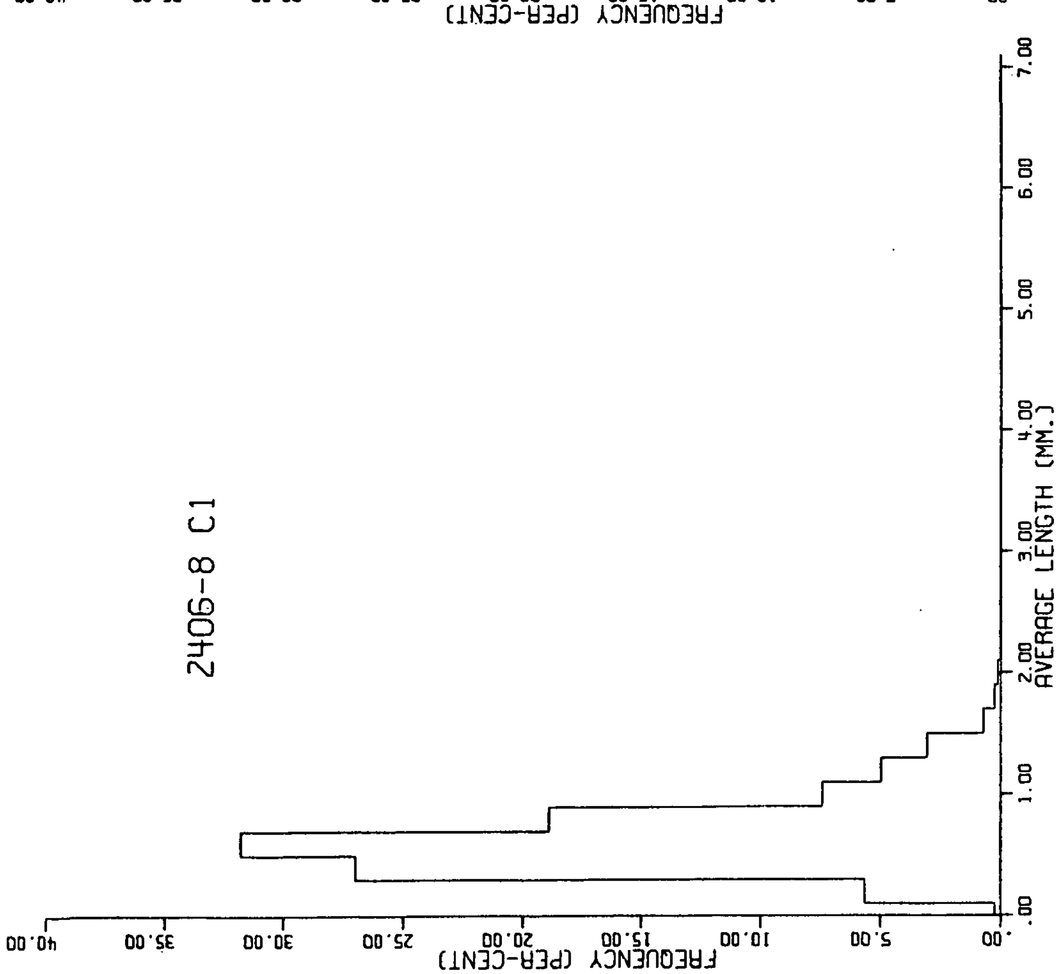


Figure 71. Fiber Length Distribution for Bleached Northern Hardwood Sulfate (Stockpile Pulp C - Unbeaten)

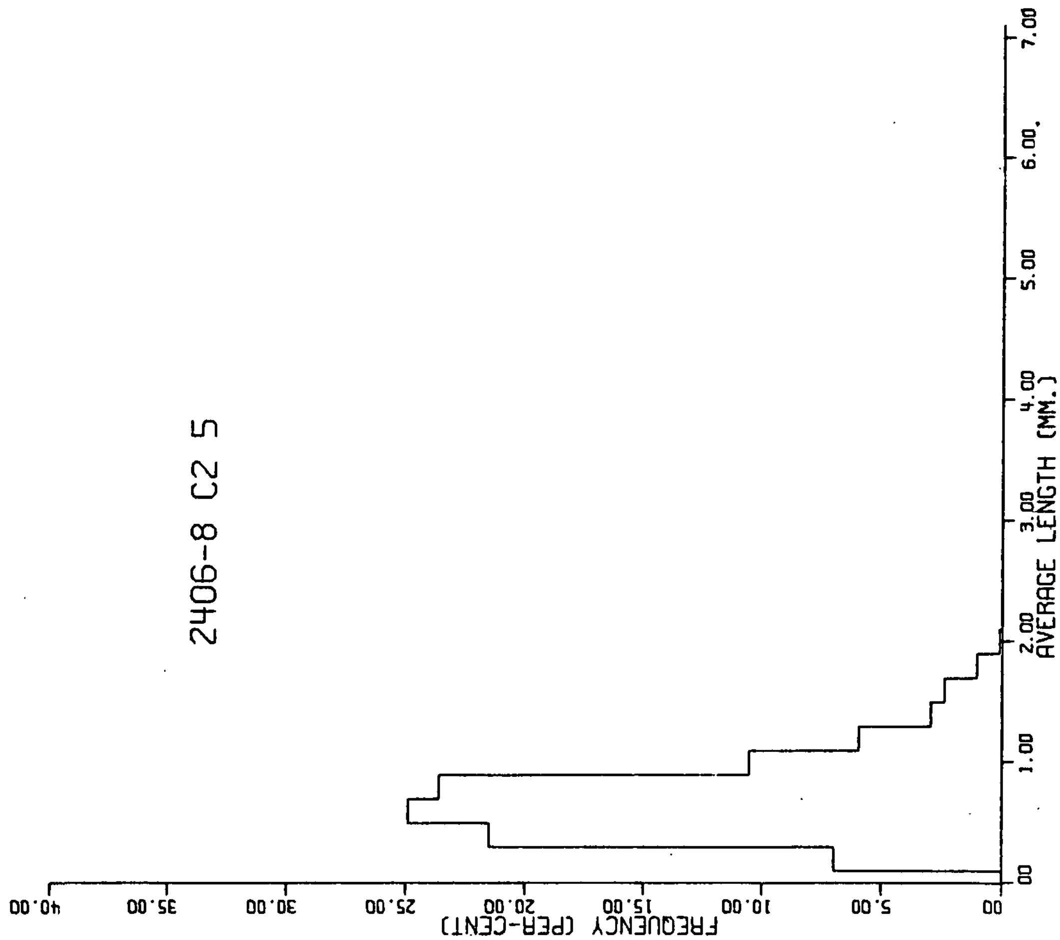


Figure 72. Pulp C Beaten for 5 Minutes

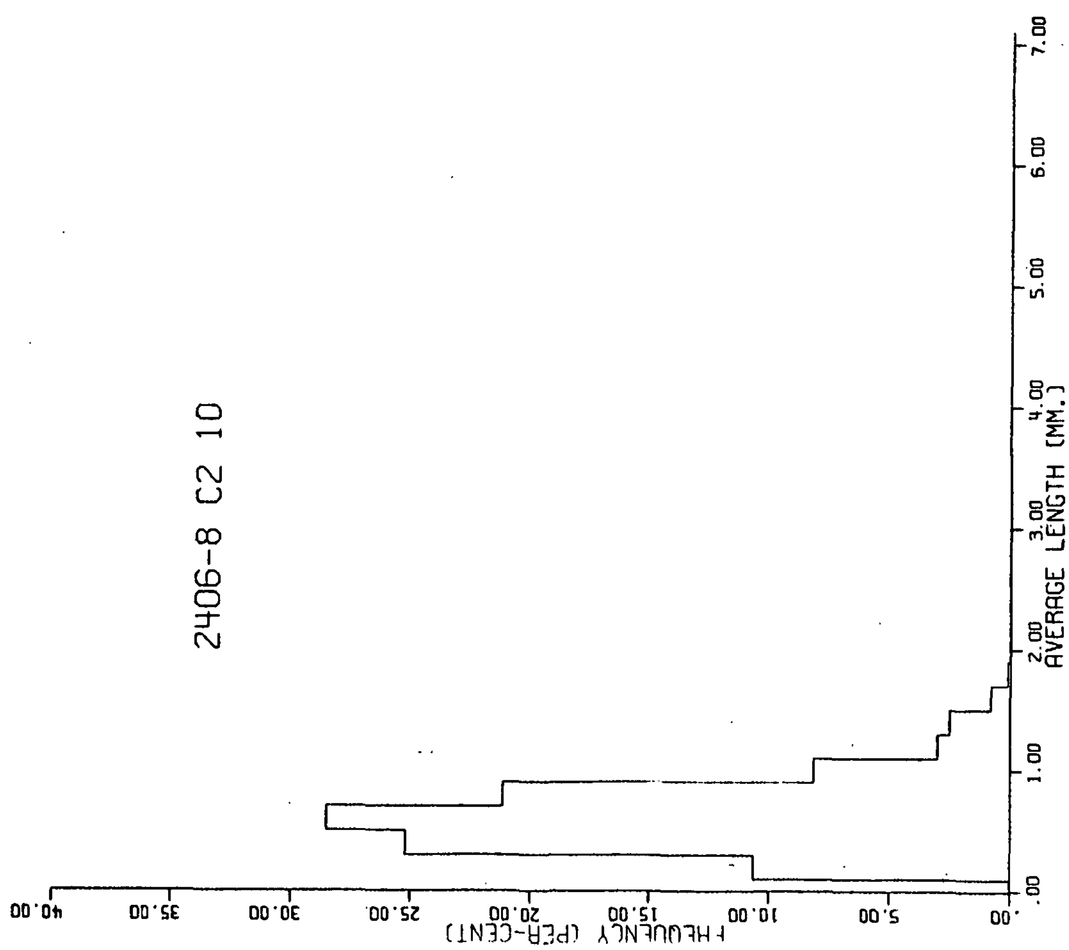


Figure 73. Pulp C Beaten for 10 Minutes

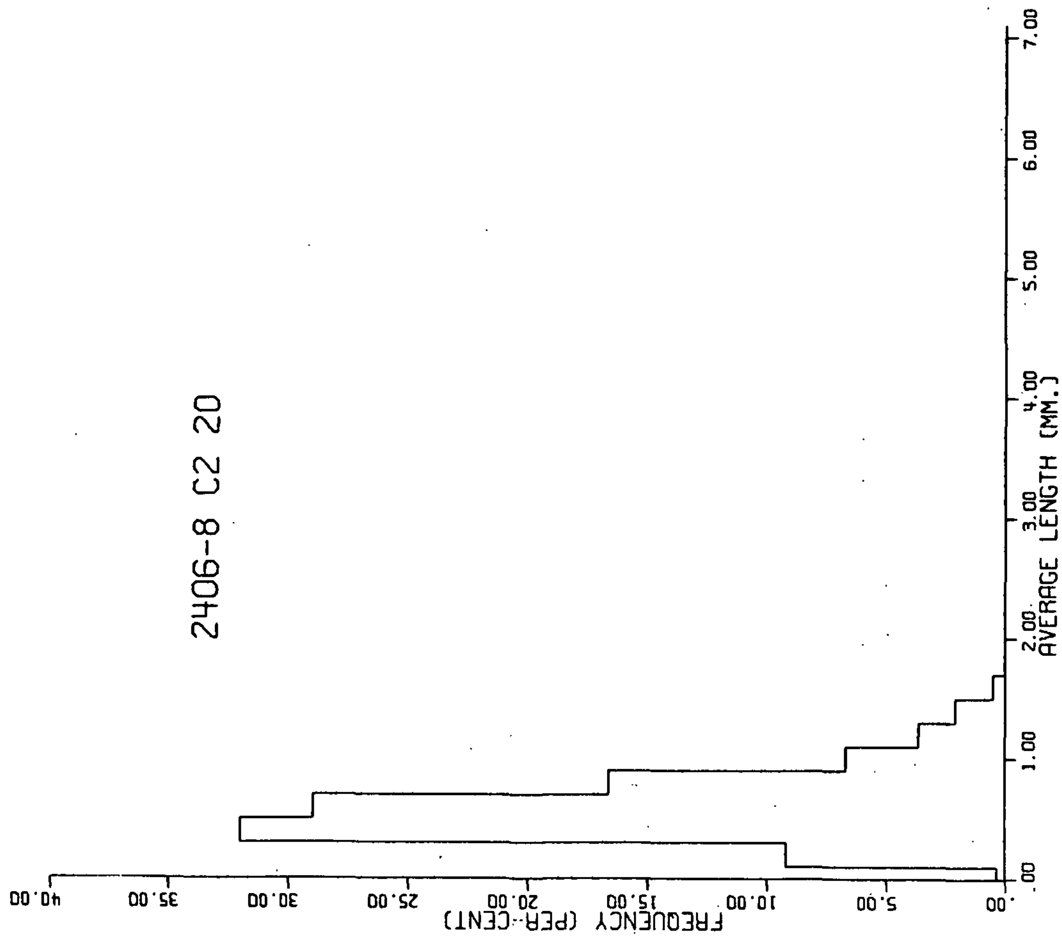


Figure 74. Pulp C Beaten for 20 Minutes

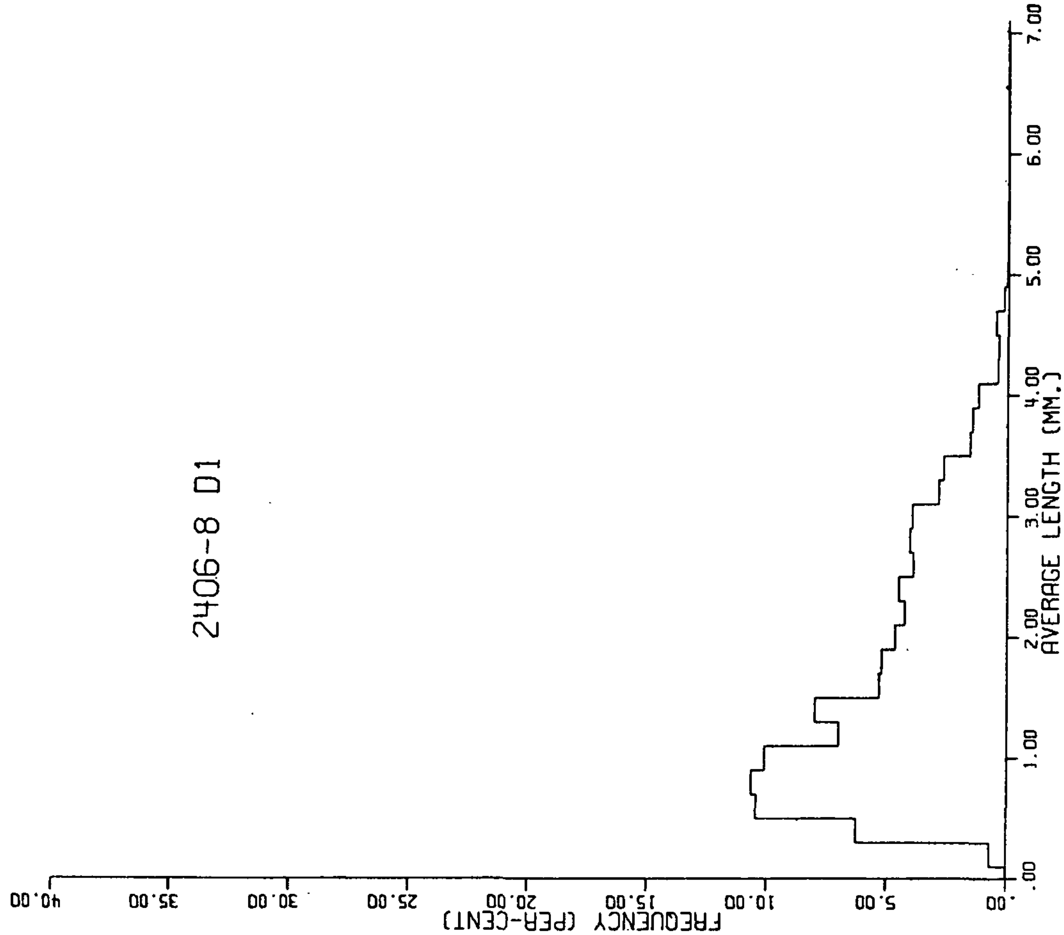


Figure 76. Fiber Length Distribution for Bleached Northern Softwood Sulfate (Stockpile Pulp D - Unbeaten)

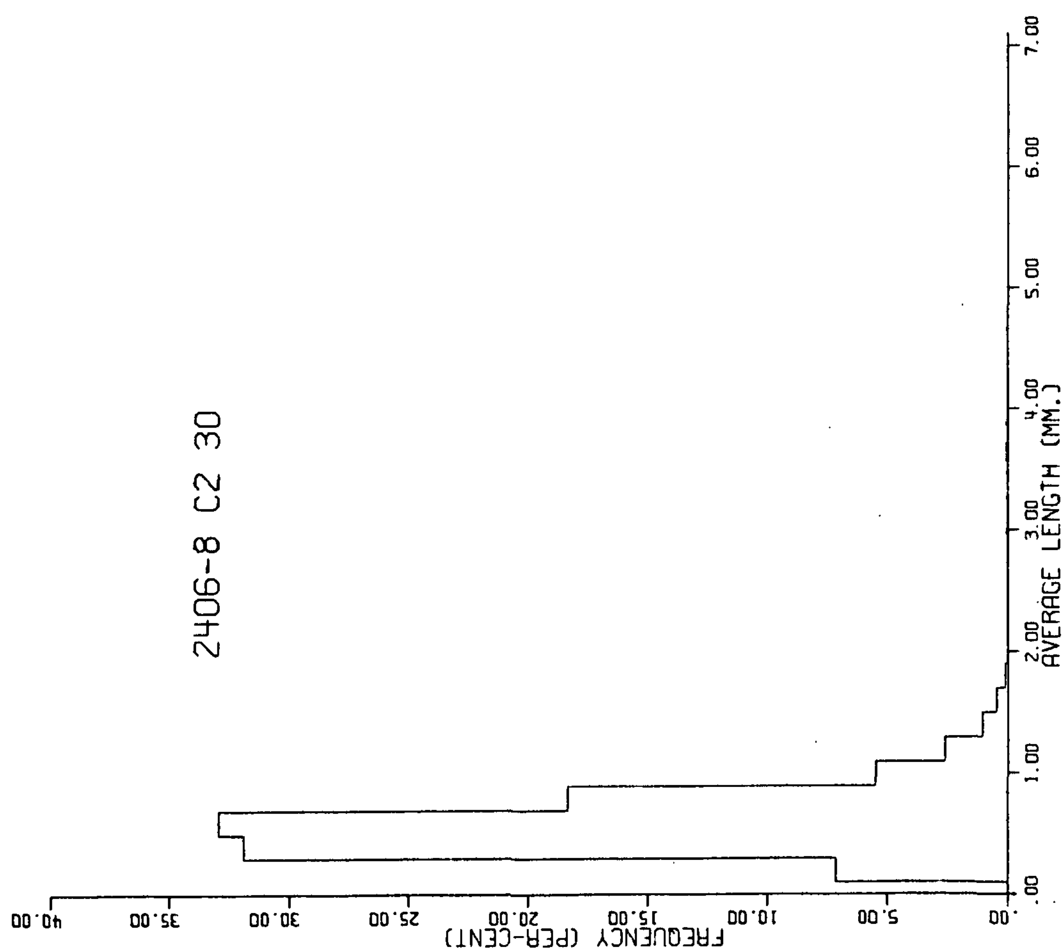


Figure 75. Pulp C Beaten for 30 Minutes

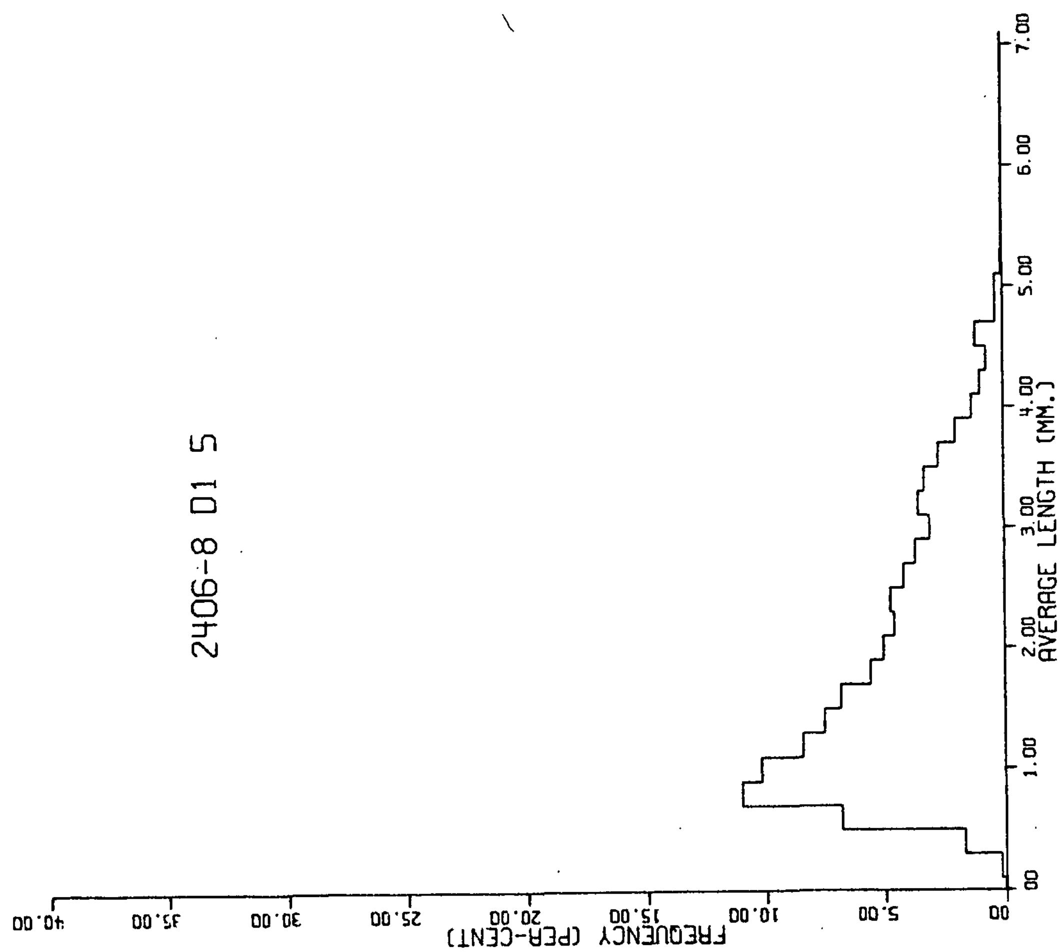


Figure 77. Pulp D Beaten for 5 Minutes

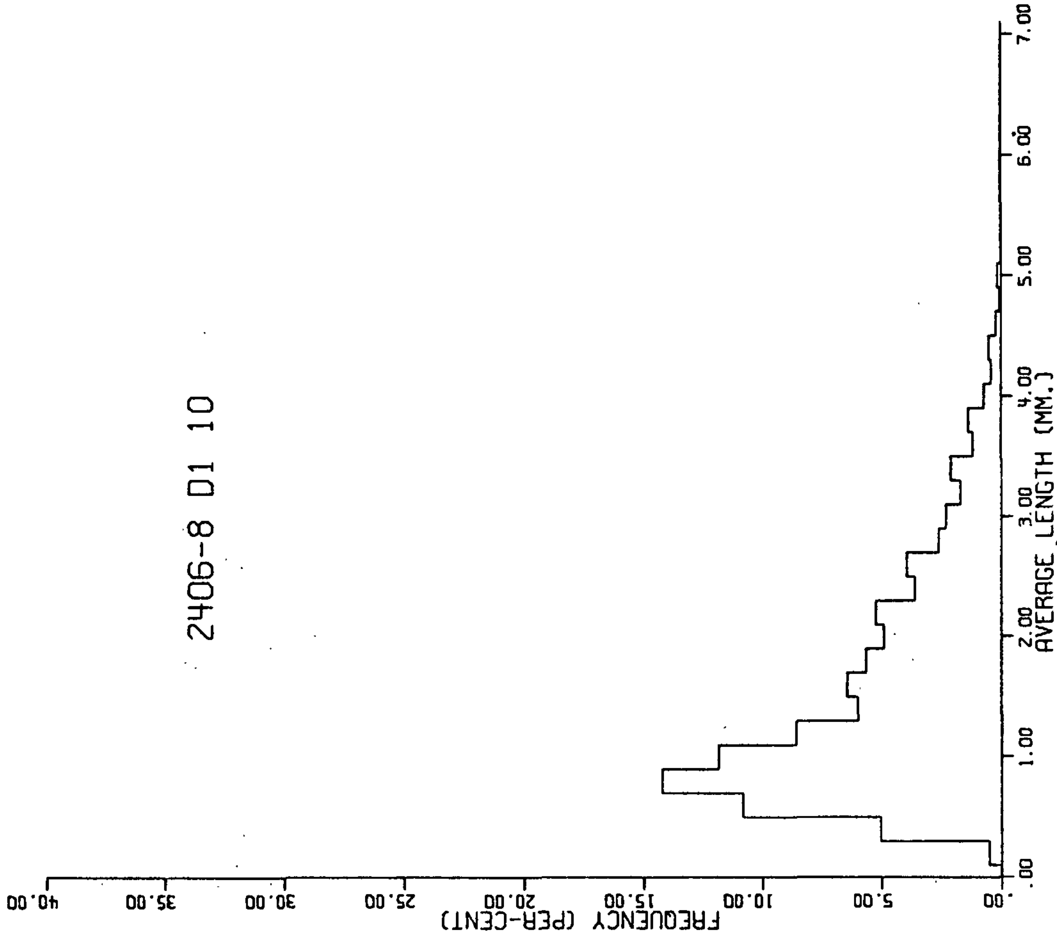


Figure 78. Pulp D Beaten for 10 Minutes

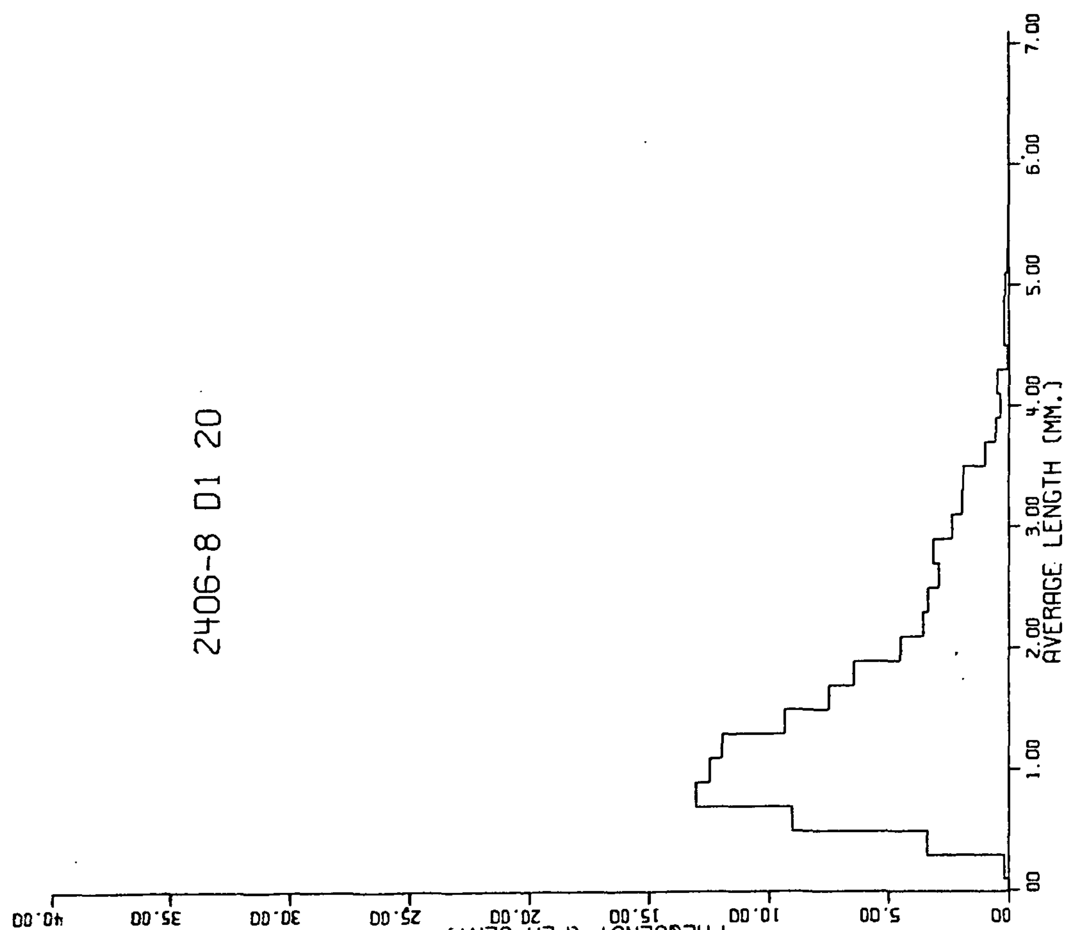


Figure 79. Pulp D Beaten for 20 Minutes

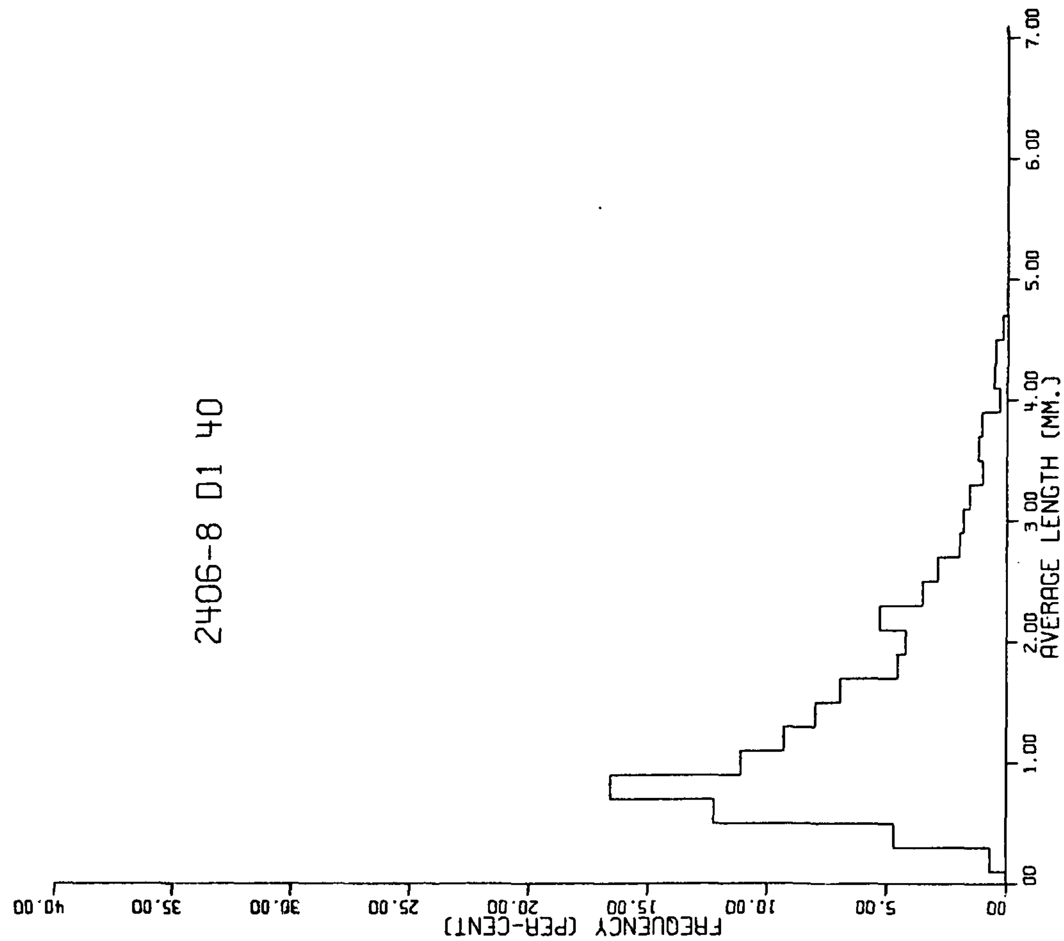
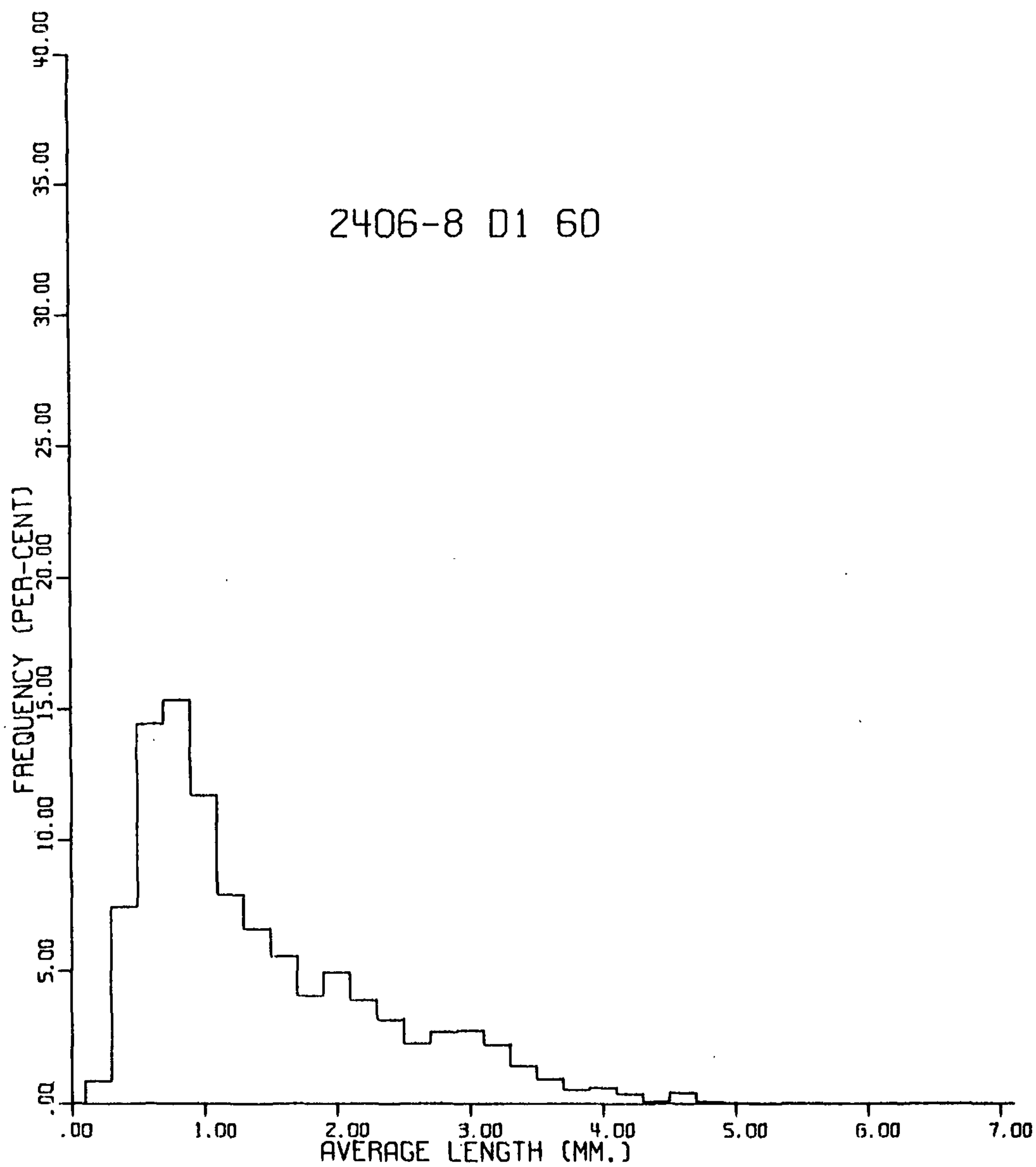


Figure 80. Pulp D Beaten for 40 Minutes



Project 81. Pulp D Beaten for 60 Minutes

APPENDIX III

BAUER McNETT SCREEN ANALYSES

TABLE VIIA

BAUER McNETT SCREEN ANALYSES FOR BLEACHED WESTERN SOFTWOOD SULFITE

Pulp Sample	Screen Fraction, % by weight				
	on 20	on 35	on 65	on 150	Remainder
A05-1[a]	59.6	18.5	10.7	4.5	6.7
-2[a]	64.5	26.3	0.3[b]	4.0	4.9
A10-1	56.7	19.5	12.3	5.4	6.1
-2	61.9	25.7	0.7[b]	2.3	9.4
A20-1	47.8	20.1	14.3	6.8	11.0
-2	51.5	33.2	0.7[b]	6.8	7.8
A40-1	34.5	20.9	18.2	9.8	16.6
-2	39.5	36.3	0.7[b]	8.6	14.9
A60-1	29.3	19.8	20.2	13.3	17.4
-2	28.8	38.9	0.6[b]	12.7	19.0

[a] Duplicate beater runs. Projection fiber-length distributions for duplicate runs were practically identical.

[b] Some untraced difficulty with apparatus or procedure.

TABLE VIIB

BAUER McNETT SCREEN ANALYSES
FOR UNBLEACHED SOUTHERN PINE KRAFT

Pulp Sample	Screen Fraction, % by weight				
	on 20	on 35	on 65	on 150	Remainder
B05-1	61.2	16.3	6.5	1.8	14.2
-2	67.1	17.6	6.3	1.9	7.1
B10-1	61.9	15.3	6.1	1.5	15.2
-2	71.0	17.0	6.8	1.7	3.5
B20-1	68.5	15.6	6.8	1.9	7.2
-2	70.1	16.8	6.6	1.7	4.8
B40-1	64.4	13.9	5.7	1.8	14.2
-2	69.3	21.6	0.2	2.4	6.5
B60-1	58.5	13.7	6.3	2.7	18.8
-2	63.5	14.7	7.2	1.4	13.2

TABLE VIIC

BAUER McNETT SCREEN ANALYSES
FOR BLEACHED NORTHERN HARDWOOD KRAFT

Pulp Sample	Screen Fraction, % by weight				
	on 20	on 35	on 65	on 150	Remainder
C05-1	0.1	48.3	25.7	12.4	13.5
-2	0.0	42.2	25.8	15.4	16.6
C10-1	0.0	42.2	23.8	12.3	21.7
-2	0.0	28.7	42.2	11.2	17.9
C20-1	0.3	41.4	21.2	13.0	24.1
-2	0.0	26.9	41.1	11.8	20.2
C30-1	0.2	40.4	22.5	16.2	20.7
-2	0.6	34.1	24.4	16.3	24.6

TABLE VIID

BAUER McNETT SCREEN ANALYSES
FOR BLEACHED NORTHERN SOFTWOOD KRAFT

Pulp Sample	Screen Fraction, % by weight				
	on 20	on 35	on 65	on 150	Remainder
D05-1	69.4	18.2	7.4	2.9	2.1
-2	75.1	19.3	8.0	2.3	--[a]
D10-1	72.2	18.6	8.3	2.4	--[a]
-2	70.6	18.2	9.9	2.8	--[a]
D20-1	69.3	16.9	8.5	2.4	2.9
-2	74.6	16.5	9.3	2.6	--[a]
D40-1	62.2	20.5	10.1	3.0	4.2
-2	65.4	18.8	11.6	3.5	--[a]
D60-1	57.5	21.8	10.1	4.0	6.6
-2	53.5	21.6	10.4	3.8	10.7

[a] Total greater than 100%. Probably due to differences in oven drying of sample cloths and pulps.

APPENDIX IV

LIST OF FIGURES AND TABLES